USAAVLABS TECHNICAL REPORT 68-88

T63 REGENERATIVE ENGINE PROGRAM (EXTENDED ENDURANCE AND ENVIRONMENTAL TESTING)

By

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December 1968

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-293(T)
ALLISON DIVISON, GENERAL MOTORS
INDIANAPOLIS, INDIANA

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The object of this contractual effort was to perform additional testing on a regenerative engine to determine environmental effects on performance and structural integrity.

This report was prepared by Allison Division of General Motors Corporation under the terms of Contract DA 44-177-AMC-293(T). It describes the tests performed and the results of those tests. Discussion is presented in areas of endurance, sand and dust erosion, carbon fouling, and noise generation.

The regenerative engine demonstrated the ability to meet performance requirements under all conditions tested. No significant adverse effects were noted that would be attributable to the regenerative engine system.

This report has been reviewed by technical personnel of this Command, and the conclusions and recommendations contained herein are concurred in by this Command.

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Contract DA 44-177-AMC-293(T)
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T63 REGENERATIVE ENGINE PROGRAM
(EXTENDED ENDURANCE AND ENVIRONMENTAL TESTING)

EDR 5380, ADDENDUM I

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ABSTRACT

This report is a supplement to USAAVLABS Technical Report 68-9. It covers the additional regenerative engine testing accomplished to determine environmental effects on the performance and structural integrity of the regenerators. The additional testing was done on the same hardware purchased under the original contract.

The third set of regenerators successfully completed a 150-hour endurance test on the first attempt with no indication of regenerator performance deterioration or loss in structural integrity. The regenerators accumulated a total of 191 hours and in excess of 278 starts and 4500 accelerations. Overall engine performance was within the 5% allowable depreciation at the completion of the test.

The second set of hardware successfully completed carbon fouling and sand and dust ingestion tests with no performance loss due to carbon fouling or any evidence of erosion or loss in structural integrity due to sand and dust ingestion.

The analysis of the sound survey data obtained under the original contract indicated that the regenerative engine perceived noise level was one to three decibels lower than that of the nonregenerative engine when installed in the YOH-6A helicopter.

The additional testing covered in this report again demonstrated the feasibility of a regenerative engine as a powerplant for aircraft operation. No problems were encountered which would indicate that a regenerative engine would be more susceptible to performance depreciation than the standard T63 engine.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

Figure		Page

Figure		Page

LIST OF TABLES

LIST OF SYMBOLS

db	Decibels
$HP/\delta\sqrt{\theta}$	Horsepower corrected to standard day conditions
H_z	Frequency—cycles per second
N_1	Gas producer speed—rpm
N_2	Power turbine speed—rpm
$N/\sqrt{\theta}$	Rotational speed corrected to standard day conditions—rpm
p	Sound pressure—Newtons/meter^2
PNdB	Perceived noise—db
r	Hemispherical radius—meters
sfc	Specific fuel consumption—lb/fuel/horsepower-hour
W	Sound power—watts
β	Azimuth angle—degrees
δ	Ratio of compressor inlet pressure to standard sea level pressure
$\frac{\Delta P}{P} \times 100$	Pressure loss—%
η_e	Regenerator effectiveness—%
θ	Ratio of compressor inlet temperatur to standard sea level temperature
ρc	Characteristic impedance of air = 410 Newtons—seconds/meter^3

INTRODUCTION

Application of regeneration to the small gas turbine can provide a significant improvement in Army aircraft range capability and in fuel logistics. However, very little is known about regenerator performance under actual operating conditions.

The original program under this contract was divided into three phases. Phase I consisted of the design and fabrication of the regenerator and required engine modifications. A "bolt-on" type regenerator requiring a minimum of engine and aircraft modifications was designed and fabricated. Phase II encompassed the engine testing required to ensure the flightworthiness of the regenerative engine. Phase III included modification of a YOH-6A helicopter and the flight test of the regenerative engine powered helicopter throughout its operating range.

The regenerator hardware completed the original program in excellent condition. Since the hardware was available for further investigation, the original contract was modified to cover additional testing. The basic purpose of the additional testing was to determine environmental effects on the performance and structural integrity of the regenerators.

This additional work included a 150-hour endurance test, a carbon fouling test, a sand and dust ingestion test, and a sound survey analysis.

150-HOUR ENDURANCE TEST

The 150-hour endurance test was run using engine S/N 400060, which incorporated the third set of regenerators. The regenerators had accumulated a total of 36.7 hours, including 25 hours flight test, prior to the start of the endurance test. In preparing the engine for test, the regenerators were removed for visual inspection and a leakage check. The basic engine was disassembled only sufficiently to allow installation of an instrumented exhaust collector. No attempt was made to refurbish the engine after the flight test and prior to starting the endurance test. The main goal of the test was to obtain additional endurance time on the regenerators.

The endurance schedule was set up to simulate the anticipated engine operation associated with helicopter installation. The schedule was derived from data obtained during logistical evaluation tests of a light observation helicopter at Fort Rucker, Alabama, as well as from information concerning actual combat missions supplied by the Army. The 150-hour endurance schedule consisted of running the 20-hour cycle, outlined in Table I, seven and one-half times, for a total time of 150 hours. One of the typical 20-minute missions is shown in Figure 1. The 150-hour endurance schedule included 278 starts and approximately 4500 accelerations. The total time on the regenerators at completion of the endurance test was 191 hours.

TABLE I. SIMULATED FLIGHT ENDURANCE TEST SCHEDULE

Profile	Mission	No. of Cycles	Total Time (Hours)
X	Ferry	1	2:30
VII	Training	1	2:30
VIII	Observation, Target Acquisition, and Reconnaissance	1	2:30
IX	Command Control	1	2:30
I	Tactical	5	1:40
II	Tactical	5	1:40
III	Cruise	5	1:40
IV	Cruise	5	1:40
V	Cruise	5	1:40
VI	Loiter	5	1:40
			20:00

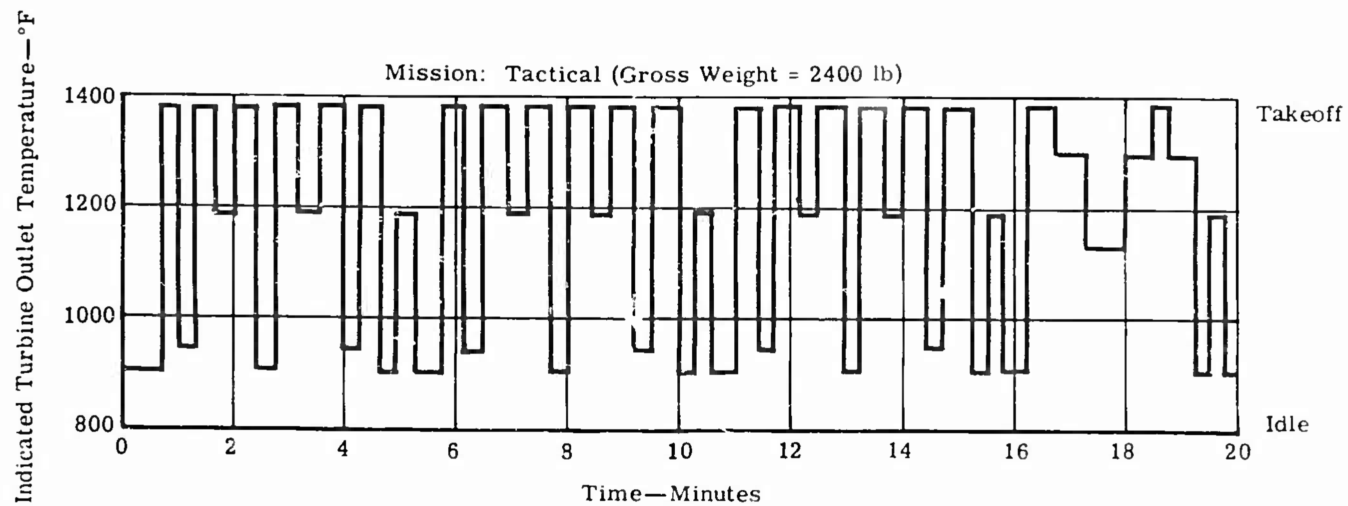


Figure 1. Simulated Flight Endurance Schedule— Profile I.

The 150-hour test was completed on the first attempt, with very few problems being encountered on either the engine or the regenerators. Inspection of the engine during scheduled shutdowns revealed that the right-side retaining ring, which secures the regenerator air outlet duct to the outer combustion case, had slipped out of its groove. The retaining ring was reinstalled and the test was continued. The right-hand regenerator was also removed for weld repair of a cracked air inlet duct at 82 and 143 hours. Table II is a list of the unscheduled stops made due to engine malfunction.

TABLE II. 150-HOUR ENDURANCE TEST RECORD

Stop No.	Endurance Time (Hours)	Date	Remarks
156	0	4-8-68	Engine ready to start endurance.
188	18:00	4-9-68	Replaced the right-side retaining ring, which secures the regenerator air-out duct to the outer combustion case, back into the groove from which it had worked out.
241	50:00	4-11-68	Added 750 cc of oil to engine lube oil system.
277	67:30	4-15-68	Repositioned right side retaining ring (at outer combustion case) which had partially worked out.
309	80:00	4-16-68	Drained 1150 cc of oil from accessory gearbox breather bottle and added 800 cc of oil to engine lube oil system.
311	82:30	4-16-68	Removed right regenerator for repair of cracks.
347	100:06	4-18-68	Repositioned right turbine air cooling flex lines which were rubbing on outer combustion case. Slight oil leak at rear power takeoff pad.
349	102:30	4-18-68	Added 830 cc of oil to engine lube oil system.
393	130:00	4-22-68	Crack noted on right regenerator at turbine cooling air fitting.
427	143:10	4-23-68	Unscheduled stop. Right regenerator removed to repair crack at cooling air fitting.
430	145:58	4-23-68	Repositioned right-side retaining ring (at outer combustion case) which had partially worked out. Drained 935 cc of oil from accessory gearbox breather bottle.
434	150:00	4-24-68	Completed endurance run. Noted slight oil leak at rear power takeoff and fuel pump pads. Drained 125 cc of oil from accessory gearbox breather bottle.

In addition to the 150-hour endurance test, a pre- and postendurance calibration run was made at standard sea level conditions. The test results are shown in Figures 2 and 3. Engine performance at the start of the test was below the estimated performance level. However, as previously stated, no attempt had been made to refurbish the engine to ensure estimated performance. The basic engine had accumulated a total of 515 hours at the completion of the endurance test. Of this total, 312 hours were accumulated as a regenerative engine. At 1380°F (military power) the engine depreciation was 4.1% in horsepower and 2.3% in specific fuel consumption, which is within the 5% allowable performance depreciation for the basic engine. In terms of regenerator performance, the hot side effectiveness decreased 2 to 3%, but the cold side effectiveness remained essentially the same.

The pressure drops were within 0.5% on the pre- and postendurance calibration. The regenerator performance indicated little or no depreciation in the regenerator as a result of the endurance testing.

The regenerators were pressure checked prior to and following the endurance test. At 20 psig, both the left- and right-hand regenerators had a leakage rate well below 0.0045 pound per minute on both checks, indicating that all tubes and braze joints were intact.

The regenerators were photographed prior to and after the 150-hour endurance test. At the completion of the test, there was a light deposit of carbon on the tubes but no evidence of buckling of any of the individual tubes in the core. In fact, the carbon deposit was heavier prior to starting the test than it was after the completion of the 150-hour endurance test. The last hour of flight testing consisted of low-power operation, which increases the accumulation of soft carbon. However, the postendurance calibration was terminated with the maximum power operation. Thus, most of the carbon was burned off. Condition of the regenerator core is shown in Figures 4 and 5.

The regenerator on the right side was removed twice during the endurance test for weld repair of cracks that developed in the inlet air duct at the auxiliary turbine cooling air fitting; a loss of power of 9 to 13% at 1380°F TOT resulted. The weld beads show the location of these cracks in Figure 6.

Other cracks of a minor nature occurred in the exhaust ducting but were of no consequence with regard to performance. The exhaust duct cracks are shown in Figure 7.

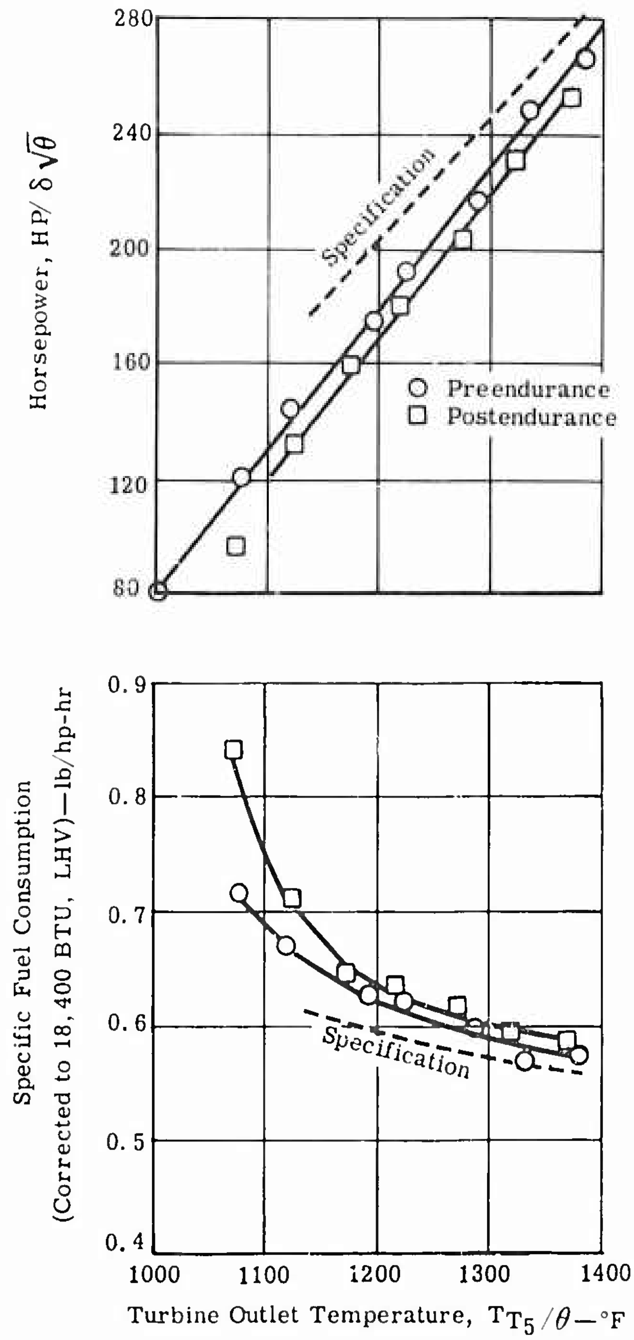


Figure 2. Pre- and Postendurance Calibration Results.

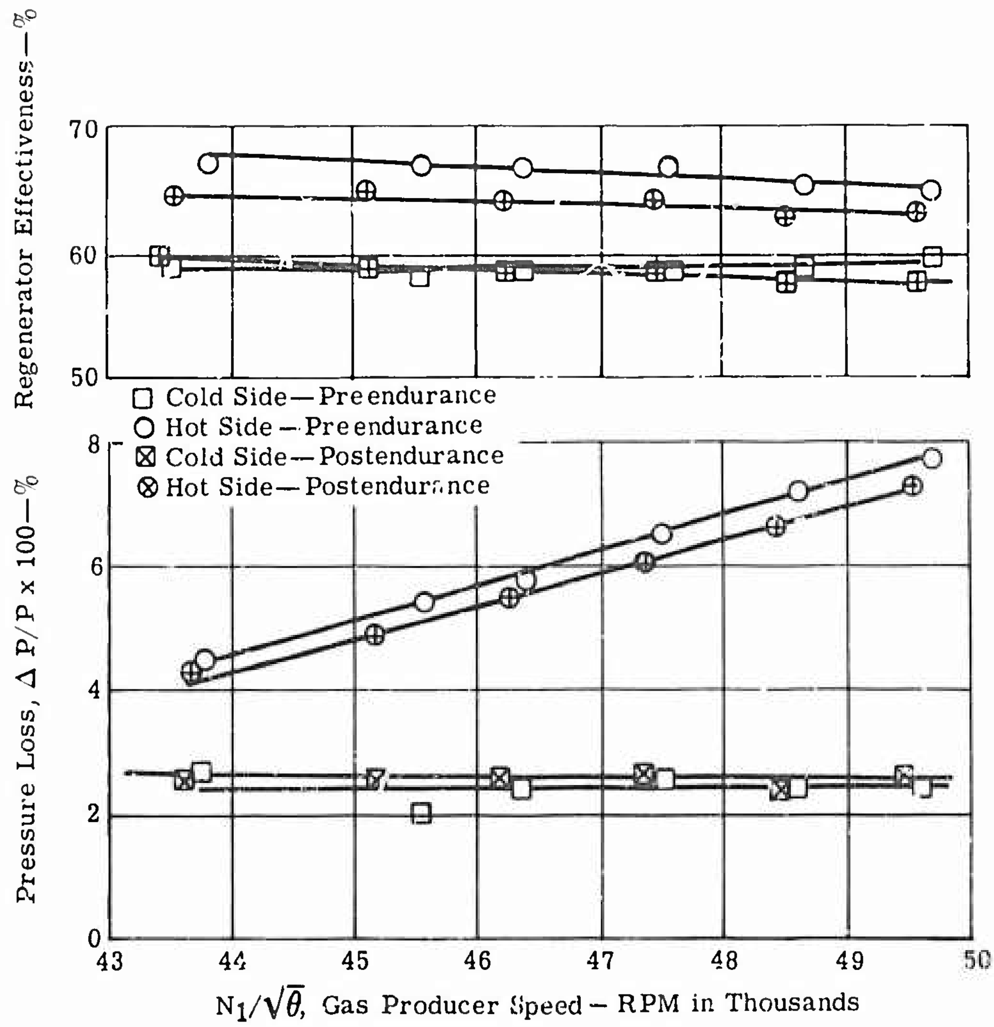


Figure 3. Pre- and Postendurance Calibration Results.

The regenerators successfully completed a 150-hour endurance test with no evidence of serious deterioration. The sheet metal cracks in the air inlet duct could be eliminated by use of a doubler between the duct and the fitting. The exhaust ducting cracks were a result of wrinkles in the sheet metal which would be eliminated by production tooling.

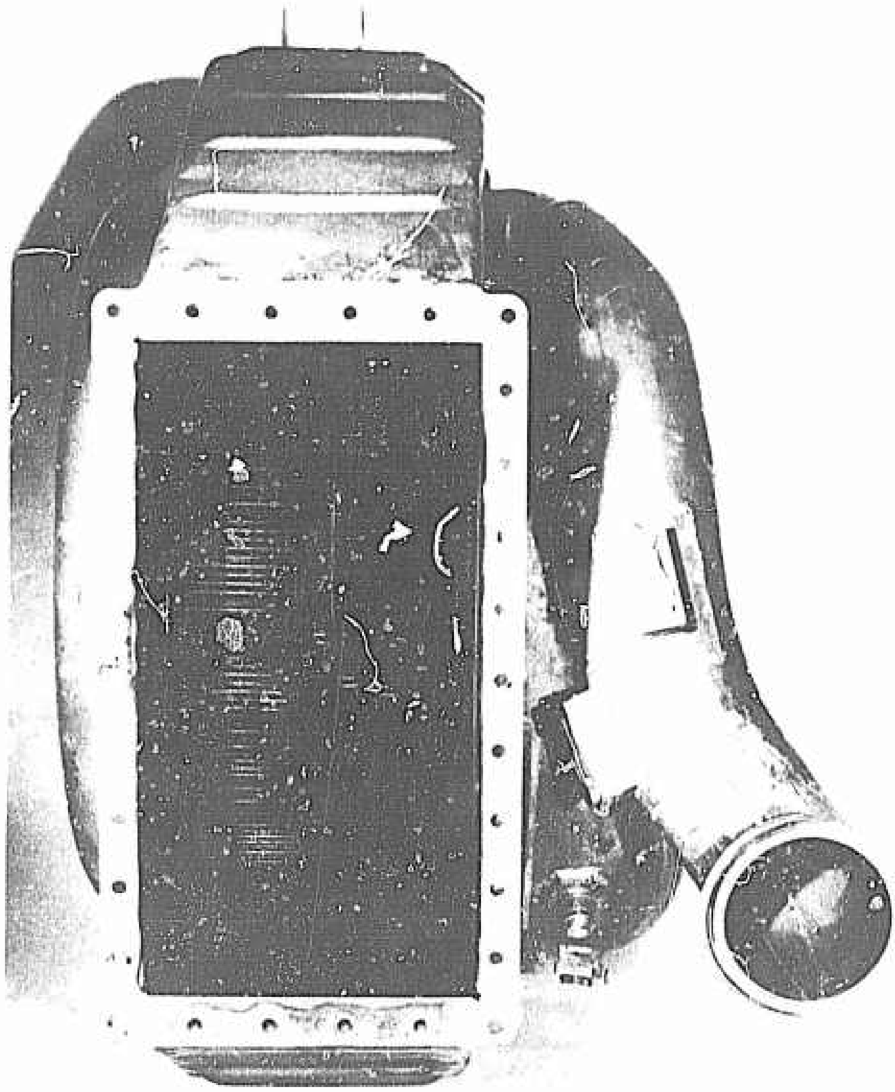


Figure 4. P/N 6858369 Regenerator Prior to 150-Hour Endurance Test.

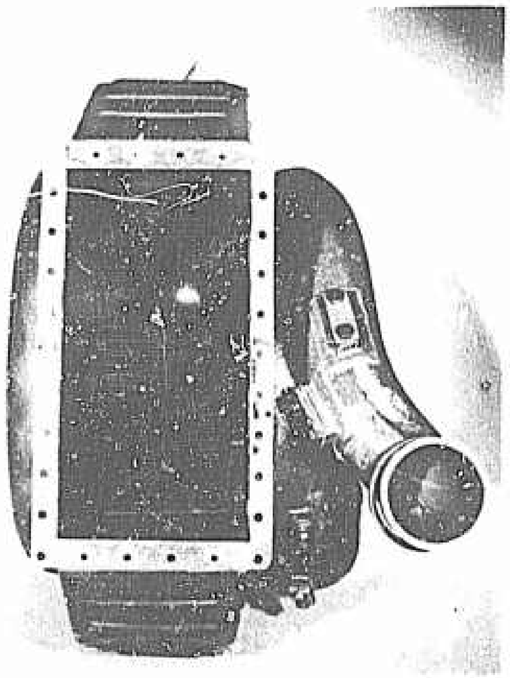


Figure 5. P/N 6858369 Regenerator After 150-Hour Endurance Test.

Figure 6. Weld-Repaired Air Inlet Duct.

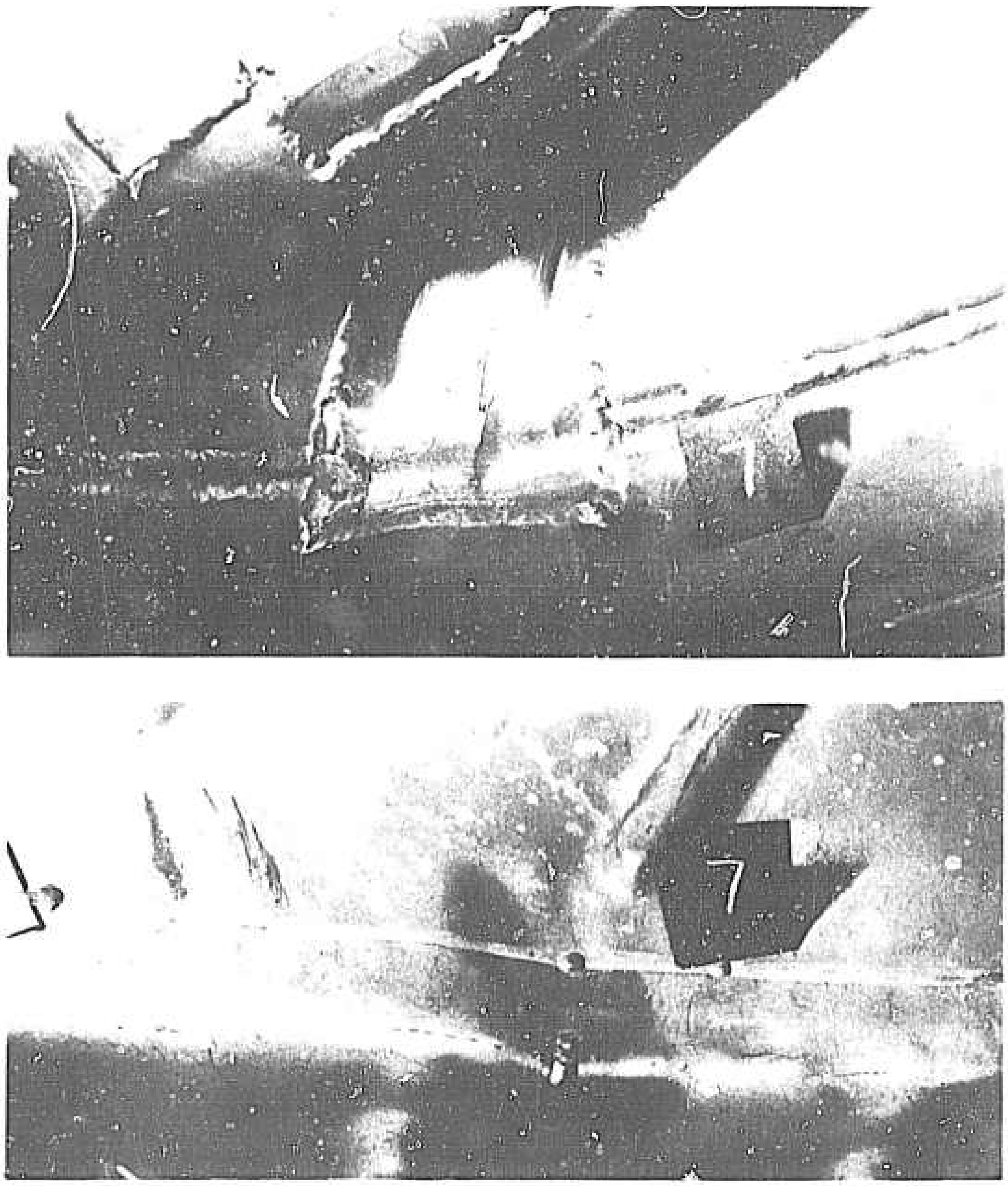


Figure 7. Exhaust Duct Cracks.

CARBON FOULING TEST

No indication of carbon fouling was encountered during the 150-hour test. However, it is known that carbon buildup will be most prevalent during idle running. Therefore, a test program was set up to determine if extended idle running would build up an excessive amount of carbon on the outside of the tubes which would result in performance depreciation. The second portion of the test consisted of high power running to determine if the buildup could be eliminated by running at high power. Table III outlines the test schedule.

TABLE III. CARBON FOULING TEST SCHEDULE

	Time (Hours)
Preendurance Calibration	3
Engine Operation at Idle	3
Postendurance Calibration	3
Engine Operation at 55% Power	5
Engine Operation at Normal Power	2
Engine Operation at Takeoff Power	1
Total	17

Engine S/N 400067 with the second set of regenerators was used for this portion of the test program. This engine was originally intended for use as spare parts. Again, no attempt was made to refurbish the engine except to install the instrumented exhaust collector. The second set of regenerators had completed 63.5 hours (including the 50-hour flightworthiness test) prior to starting the carbon fouling test. The regenerators were in excellent condition, with no leakage in any of the tubes or braze joints.

The engine was installed for the carbon fouling test. After completion of the calibration, engine oil consumption increased suddenly. Five quarts of oil were used in 15 minutes operation. It was suspected that the No. 5 carbon seal had failed, allowing oil to enter the exhaust collector and pass through the regenerator.

The engine was removed and the turbine disassembled. The carbon seal was leaking slightly, but the majority of the oil consumption was due to a plugged scavenge oil tube in the power turbine support. In the T63-A-5

engine, the scavenge oil strut has an oil tube that extends up into the hollow strut. This tube was found to be plugged. Engine S/N 400060, which had completed the 150-hour test without plugging, did not have this tube installed. Engine S/N 400067 was completely cleaned and assembled without the scavenge oil tube and with a new carbon seal installed. The engine completed the rerun of the preendurance calibration test schedule, but high oil consumption was again encountered after completion of the calibration. The external sump was found to be plugged. The sump was replaced, and a glass bottle was installed so that the oil flow from the sump could be monitored. High gearbox pressure indicated the possibility of a worn air-oil seal which was allowing hot gas to heat the oil sump area to the coking temperature of the oil.

The test program was continued. A total of 3 hours was completed at idle speed to build up carbon on the regenerator core. Engine oil consumption during this period and also during the postendurance calibration was negligible. However, oil consumption again increased during the last data point and five quarts of oil were used in approximately 15 minutes operation.

The pre- and postendurance calibration, shown in Figures 8 and 9, indicated no depreciation in engine performance after 3 hours' running at idle. Performance at takeoff temperature (1380°F TOT) was 284 horsepower and 0.55 specific fuel consumption. Regenerator performance indicated no change in effectiveness and only 0.1 to 0.2% increase in pressure drop on the hot side. Since the data indicated no depreciation in performance, the last 8 hours of the test schedule were deleted. The test program indicated that with a clean-burning engine and proper attention to tube size and spacing of the core, no carboning problems will be encountered on a regenerative engine.

Further investigation of the oil coking problem revealed that the pressure oil nozzle in the power turbine support was flowing approximately one-third of the normal oil flow. This lower oil flow, plus the higher sump temperature associated with the worn air-oil seal, resulted in the coking of the scavenge oil system. It was found that the nozzle was partially plugged with foreign material. Replacing the pressure oil nozzle eliminated the coking problem. The subsequent sand and dust test was complete without further oil coking problems.

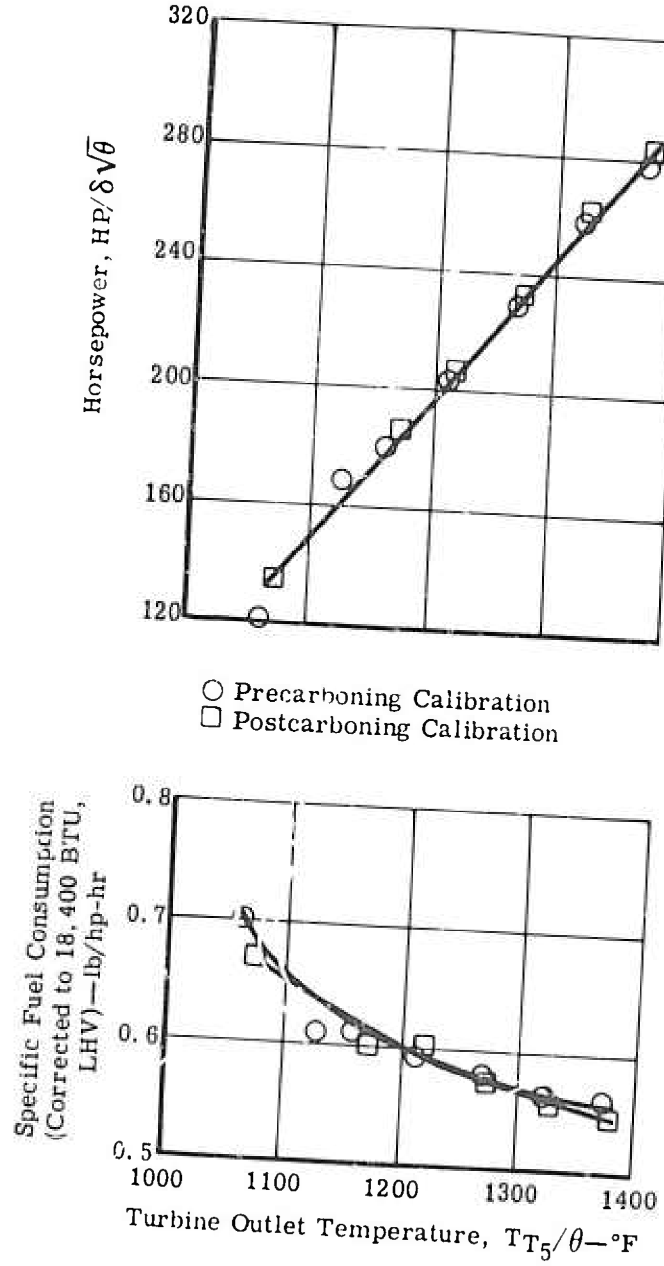


Figure 8. Pre- and Postcarboning Test Calibration Results.

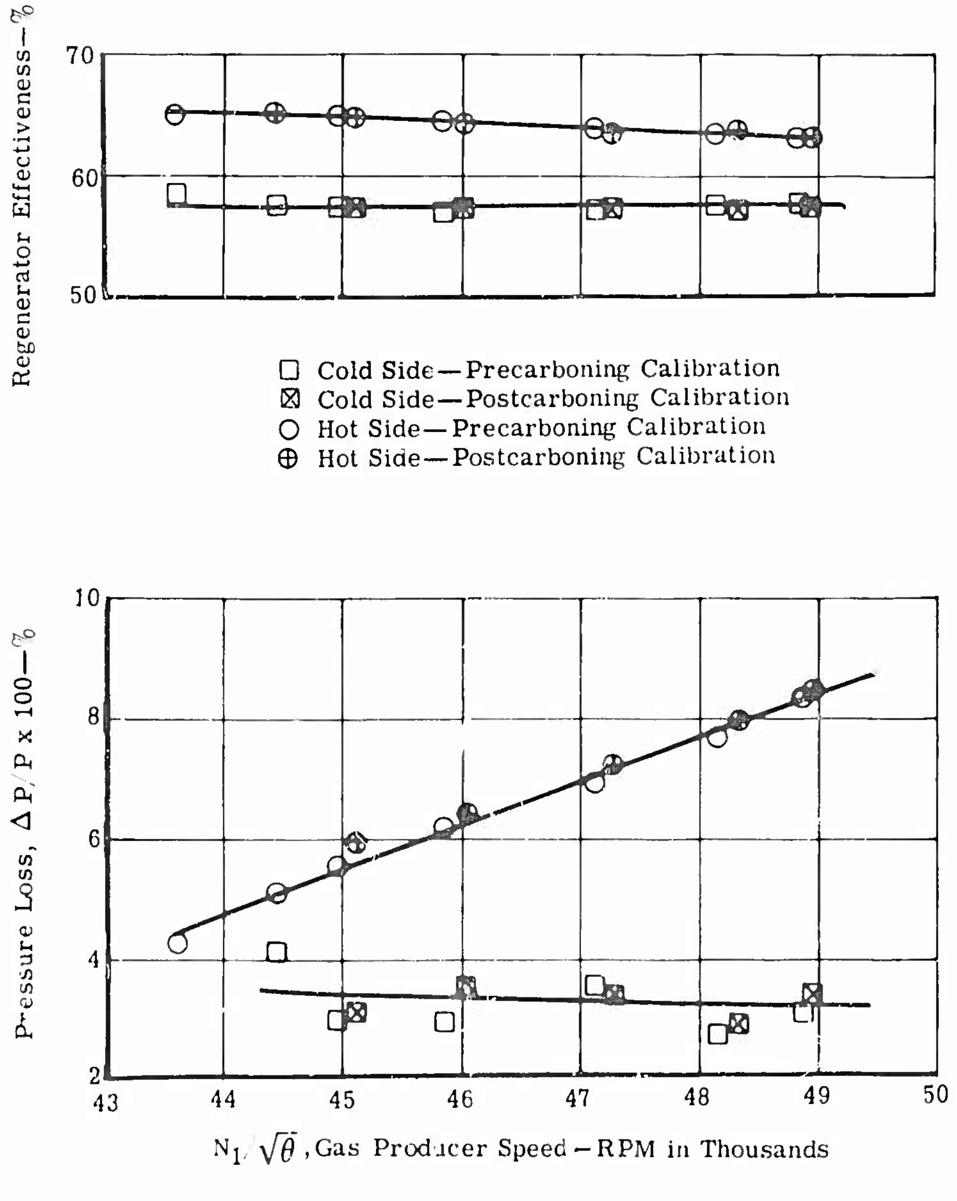


Figure 9. Pre- and Postcarboning Test Calibration Results.

As mentioned previously, approximately five quarts of oil went through the regenerators after the postendurance calibration. This oil passed through the regenerator in a liquid state as shown in Figure 10. The liquid oil removed all carbon deposits from the outside of the tubes. There was also some evidence of coked oil on the tubes at the junction of the tubes to the header. However, the high oil consumption occurred after the completion of the postendurance calibration. Therefore, the performance evaluation before and after the 3-hour idle run was valid.

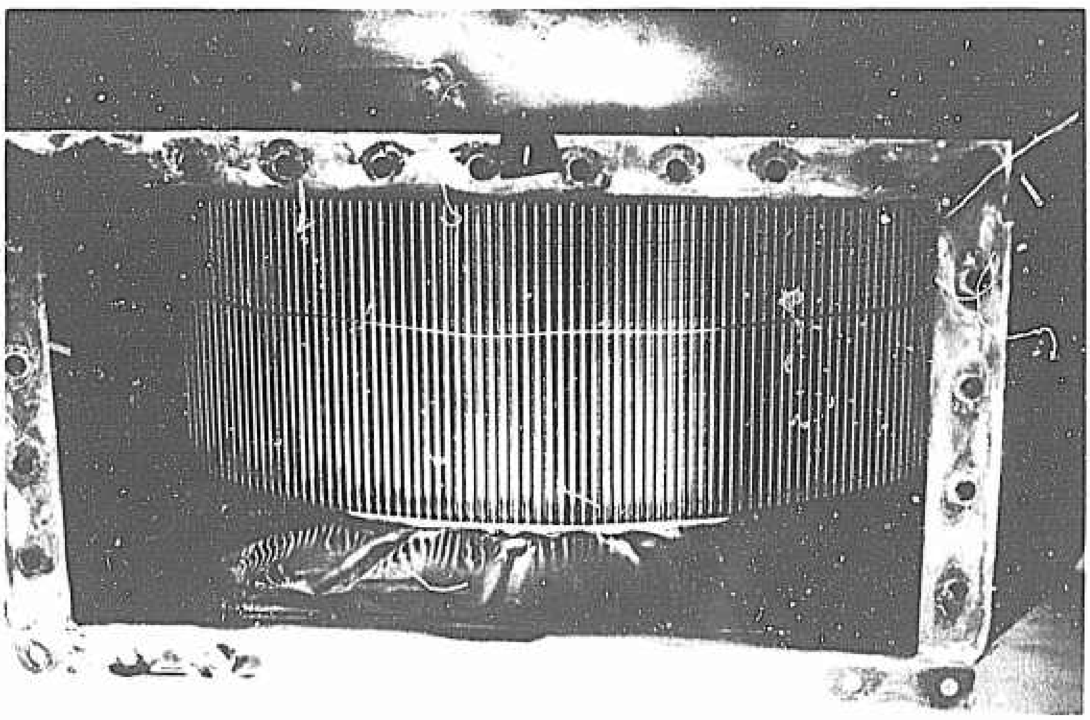


Figure 10. P/N 6858502 Regenerator After Carbon Fouling Test.

SAND AND DUST INGESTION

The sand and dust ingestion test on the regenerative engine was conducted in accordance with Allison T63-A-5A Model Specification 580-F and the Official 10-Hour Dust Ingestion Test. The object of the test program was to determine if the regenerators were capable of withstanding the same dust environment as the basic engine.

The dust used for the test was 0-200 micron A-C coarse test dust conforming to Specification MIL-A-13488B. The micron size of the dust and percent by weight are shown in Table IV.

TABLE IV. A-C COARSE DUST CONSTITUENTS

Size in Microns	Percent by Weight
0-5	12 ± 2
5-10	12 ± 2
10-20	14 ± 3
20-40	23 ± 3
40-80	30 ± 3
80-200	9 ± 3

The dust used was supplied at a rate of 0.0015 gram per cubic foot. When based on engine airflow for Normal power at standard day sea level conditions, this rate was determined to be 0.44 pound per hour. The dust rate was verified by weighing at 30-minute intervals. Total dust ingested was 4.4 pounds over the 10 hours of dust ingestion.

Ambient air was utilized throughout the dust testing, but 59° unity ram pre- and postendurance calibrations were made to verify performance depreciation.

The test schedule consisted of alternate 15-minute periods at 75% normal power with and without dust followed by 5-minute intervals without dust at normal and takeoff power. The test schedule was set up to minimize the accumulation of fused silica on the first stage turbine nozzle and combustion liner. The test schedule is outlined in Table V.

A typical dust ingestion test setup is shown in Figure 11. The dust is injected into the compressor inlet plenum where it mixes with the compressor inlet air from facilities. The dust then passes through the engine and exits, along with the exhaust gas, into the test stand exhaust duct.

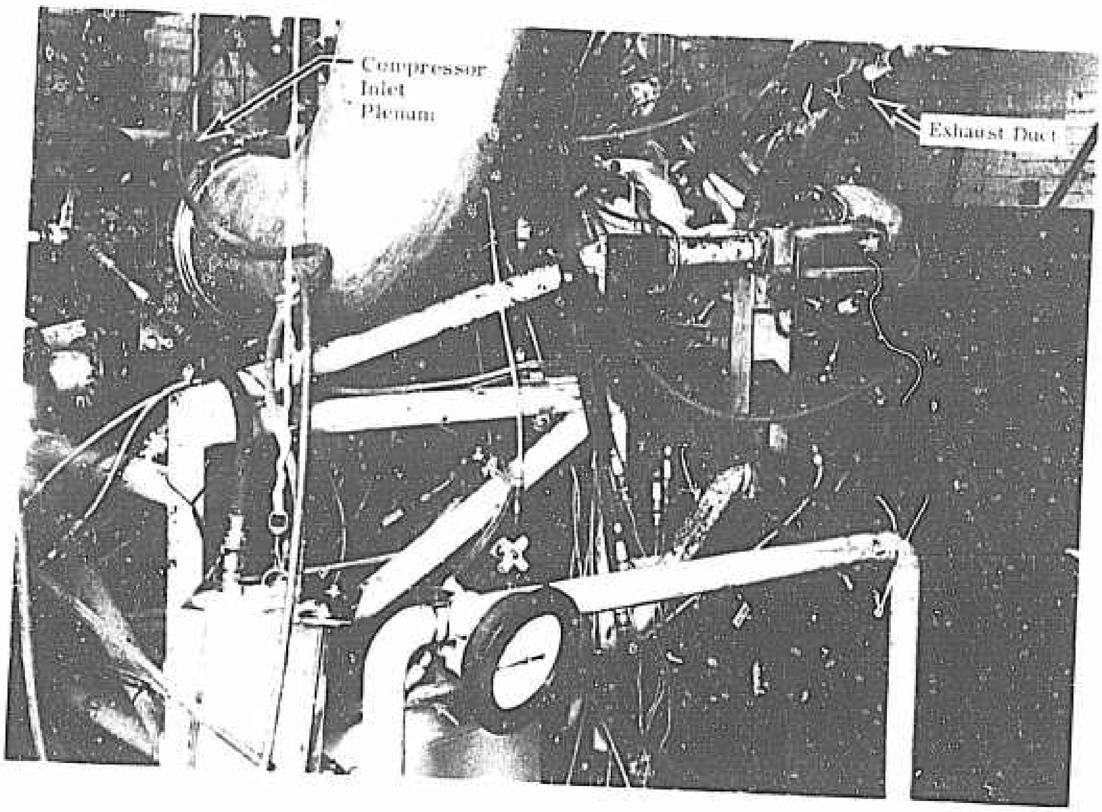


Figure 11. Dust Ingestion Test Installation.

TABLE V. SAND AND DUST INGESTION TEST SCHEDULE

A. Preingestion Calibration (standard sea level unity ram conditions)

B. Stabilize at 1148° TOT. Ingest dust at a rate of 0.44 lb/hr maintaining N_1 speed for the following schedule:

1. 15 minutes with dust on
2. 15 minutes with dust off
3. 15 minutes with dust on
4. 15 minutes with dust off
5. Shut down for 10 minutes and weigh dust ingested.
6. Fire up and stabilize at 1240° for 5 minutes; then run 5 minutes at maximum rated conditions.

C. Stabilize at 1148° TOT and run the following schedule:

1. 15 minutes with dust on
2. 15 minutes with dust off
3. 15 minutes with dust on
4. 15 minutes with dust off
5. Shut down for 1 hour and weigh dust ingested.
6. Fire up and stabilize at 1240° TOT for 5 minutes; then run 5 minutes at maximum.

D. Repeat B and C until 10 hours of dust time or 10 cycles have elapsed.

E. Postingestion Calibration (standard sea level unity ram conditions)

Figure 12 shows a close-up of the dust ingestion rig. The dust is contained in the pressurized glass bottle as shown. The bottle also incorporates a vibrator to ensure uniform feed. The dust is piped through an orifice to the aspirator. The aspirator pressure and orifice size are adjusted to provide the proper dust rate.

Prior to the dust test, the rig was calibrated to provide the proper dust rate. On this test program for the regenerative engine some difficulty was encountered in obtaining a repeatable calibration. Poor repeatability was due to the high humidity prevalent during the test. An air dryer was installed in the aspirator pressure line and the dust was oven dried prior to ingestion. With these precautions, repeatable calibrations were obtained and the test program was completed without incident. No further problems were encountered with the dust rig, engine, or regenerators.

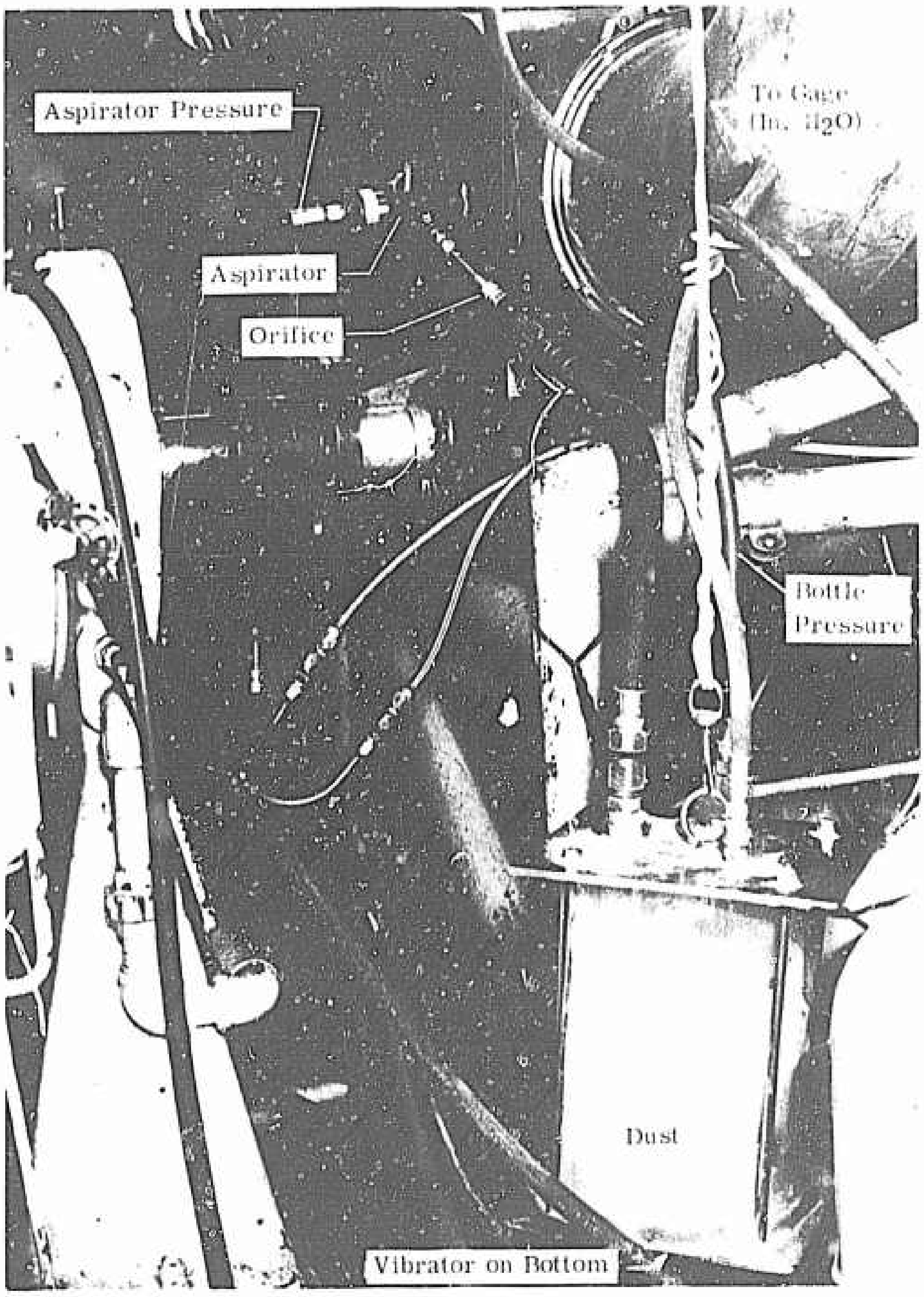


Figure 12. Dust Ingestion Test Rig.

The postendurance calibration indicated a 26% horsepower depreciation. However, the majority of this depreciation was due to buildup under the compressor impeller shroud. The T63-A-5 engine used on this test program incorporated an impeller with a full shroud. The T63-A-5A impeller incorporates a short shroud impeller which does not accumulate dust.

To obtain a true indication of the engine depreciation, one-half of the compressor case was removed and the area under the impeller shroud was cleaned. The postendurance calibration was then rerun after the impeller was cleaned. The test results are shown in Figures 13 and 14.

In terms of regenerator performance, the leakage check showed zero leakage, indicating that all tubes and braze joints were intact. The pressure drop on the hot side showed a 0.5% increase and the pressure drop on the cold side decreased 0.7%. The effectiveness on the cold side remained the same, while the hot side effectiveness decreased 2%. The changes in regenerator performance are within the accuracy and repeatability of the instrumentation.

In terms of engine performance, the depreciation was comparable with that of the T63-A-5A, as shown in Table VI. The performance depreciation for the regenerative T63 engine was approximately 2% higher than that of the T63-A-5A.

TABLE VI. PERFORMANCE DEPRECIATION COMPARISON

Horsepower	T63-A-5A		Regenerative T63-A-5	
280	12 hp	4.3%	20 hp	7.15%
239	19 hp	7.95%	22 hp	9.2%
215	21 hp	9.75%	25 hp	11.6%

One of the potential problem areas in the regenerator is dust collection in the air inlet and outlet ducts. To determine the amount of dust collected in the regenerators, the regenerators were weighed before and after the dust ingestion test. The increase in weight was 0.04 pound on the left-hand regenerator and 0.07 pound on the right-hand regenerator. This increase in weight is not considered to be significant. Figures 15 and 16 show the left-hand regenerator after the dust ingestion test. There was some indication of a scale formation on the first row of tubes (gas inlet)

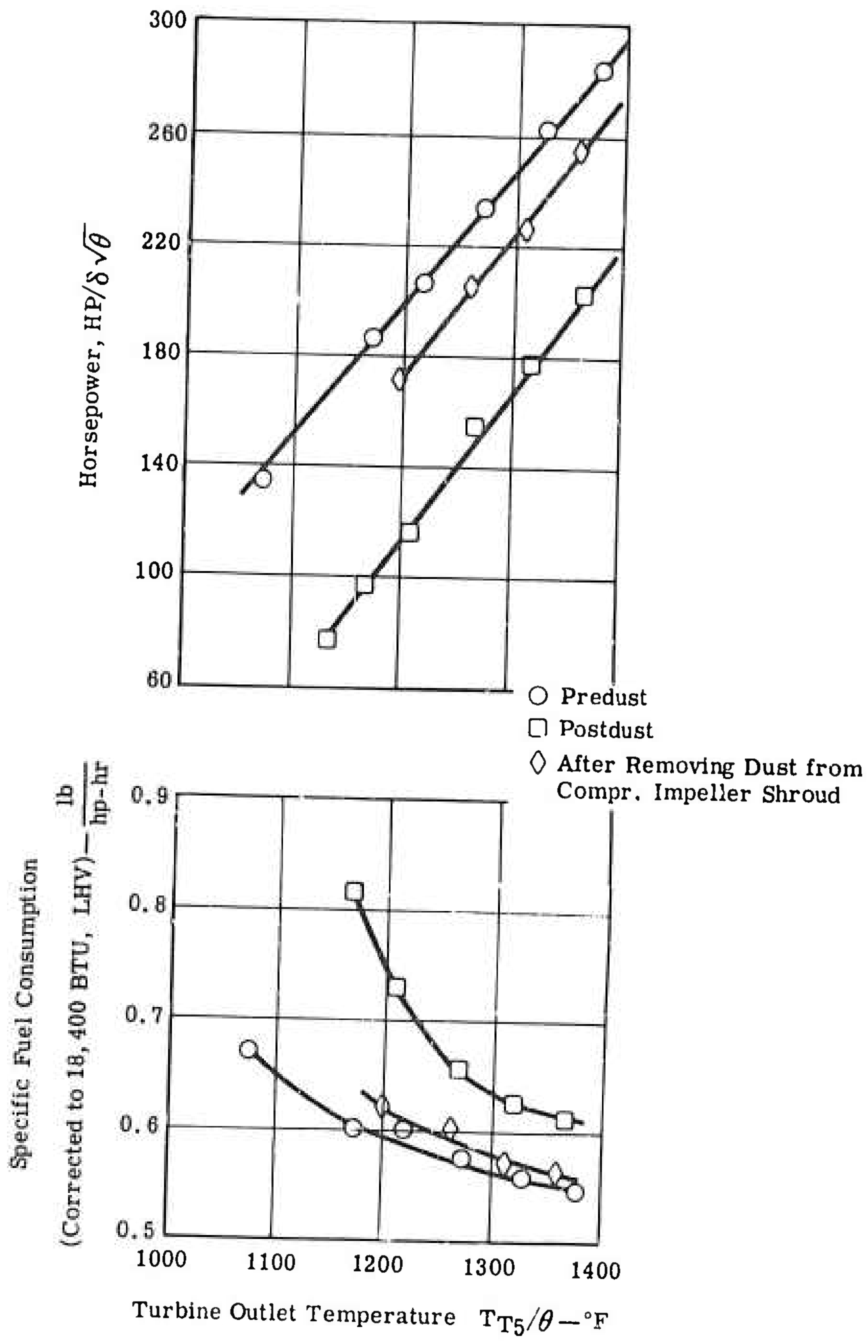


Figure 13. Predust and Postdust Ingestion Calibration Results.

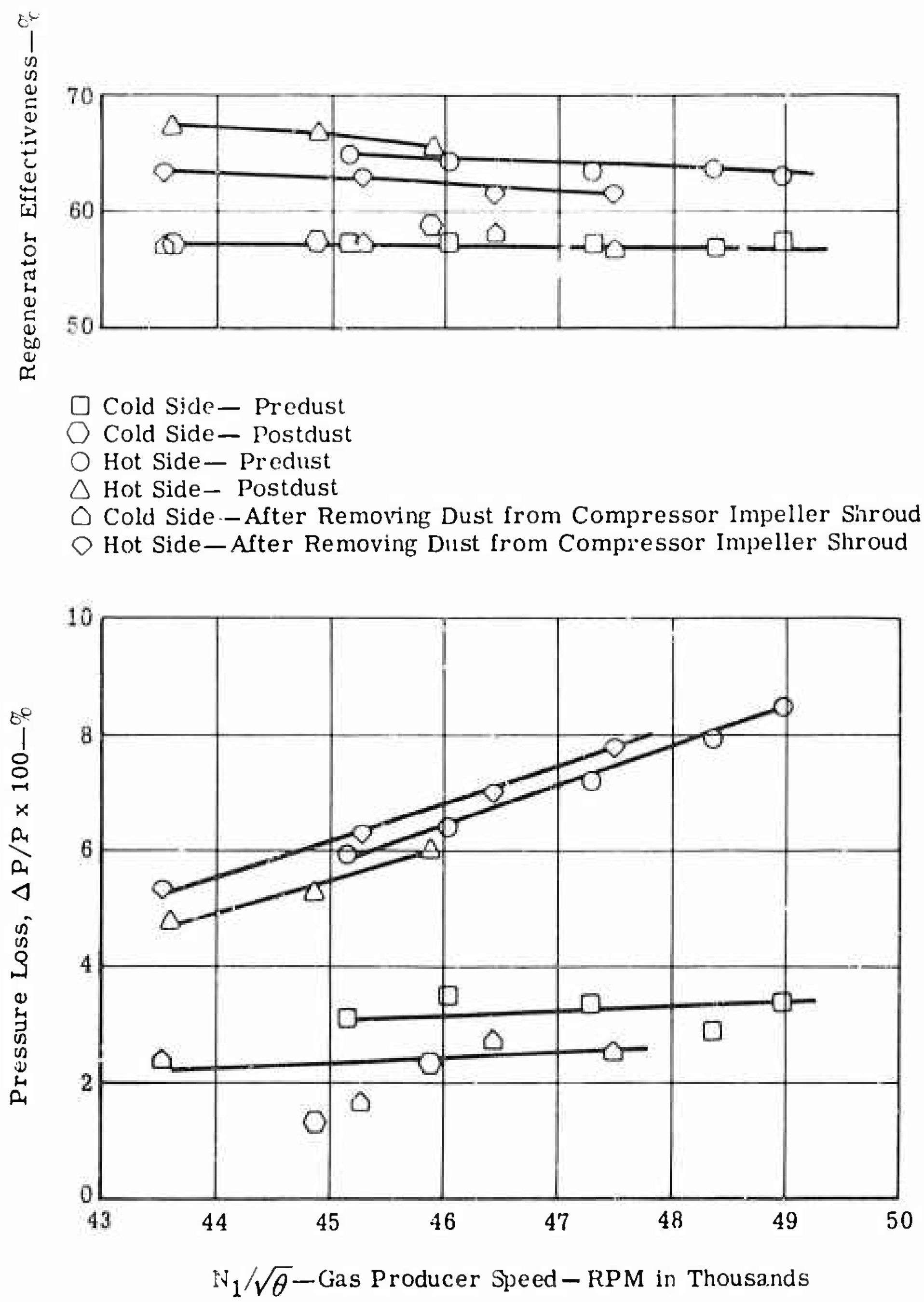


Figure 14. Predust and Postdust Ingestion Calibration Results.

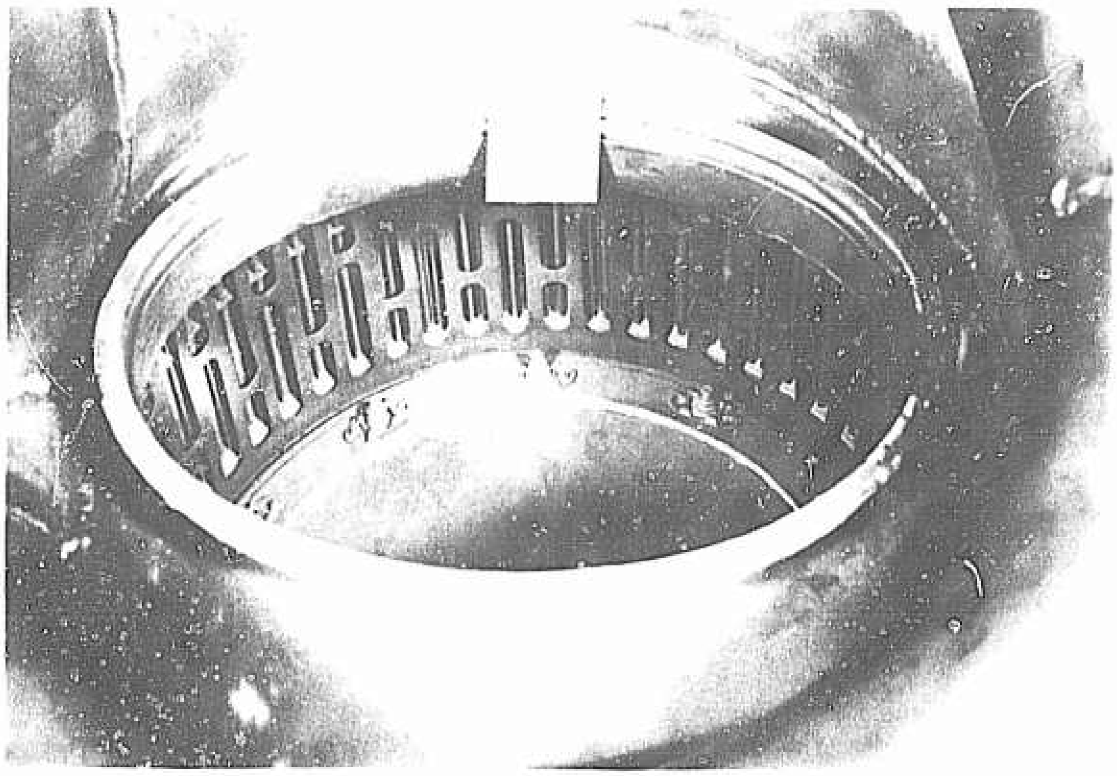


Figure 15. P/N 6858501 Regenerator (Left Side) After Dust Ingestion.

as shown in Figure 15. On the gas outlet side there was a film of dust collected, as shown in Figure 16. The tubes were wiped in the center to give some indication of the thickness of the film.

After completion of the test program, the core of the left-hand regenerator was investigated metallurgically. This investigation was directed toward obtaining evidence of erosion and corrosion. All of the ducts were removed, and the core was cut at the split header which defines the interface between the first and second pass.

Figure 17 defines the regenerator configuration and can be used to locate the areas which were photographed during the metallurgical evaluation. Figures 18 and 19 show the first pass of the regenerator core. There is an indication of surface scale on the outside of the gas inlet tubes, as shown on Figure 18. Most of the dust that had collected on the outside of the gas outlet tubes during the test had been shaken off due to normal handling.

Figures 20 and 21 show the condition of the second pass of the regenerator core. Again, there was no visual indication of erosion or damage to the tubes as a result of the dust ingestion. There was no evidence that the scale on the gas inlet side was more pronounced than the scale on the first pass.

Further investigation of the scale revealed that it could be easily brushed from the tube wall surface and was soluble in water. The scale formation extended through the first seven rows. A soap-and-water wash eliminated all the scale; however, there was still an indication of surface discoloration, as shown in Figure 22.

At the completion of the sand and dust test, the third set of regenerators had accumulated 106 hours of engine testing. Since the endurance time accumulated can be considered significant, the tubes were analyzed to determine if there was any indication of incipient corrosion or oxidation. Tube specimens were taken from rows 1, 2, 13, and 25 on both the first and second pass of the regenerator core. The specimens were mounted, ground, and inspected at up to 200X magnification.

Figure 23 shows the typical condition of the inside diameter of the tubes. All tubes in both the first and the second pass were very clean, with the exception of braze on the ID of some tubes in the vicinity of the tube-to-header braze joint.

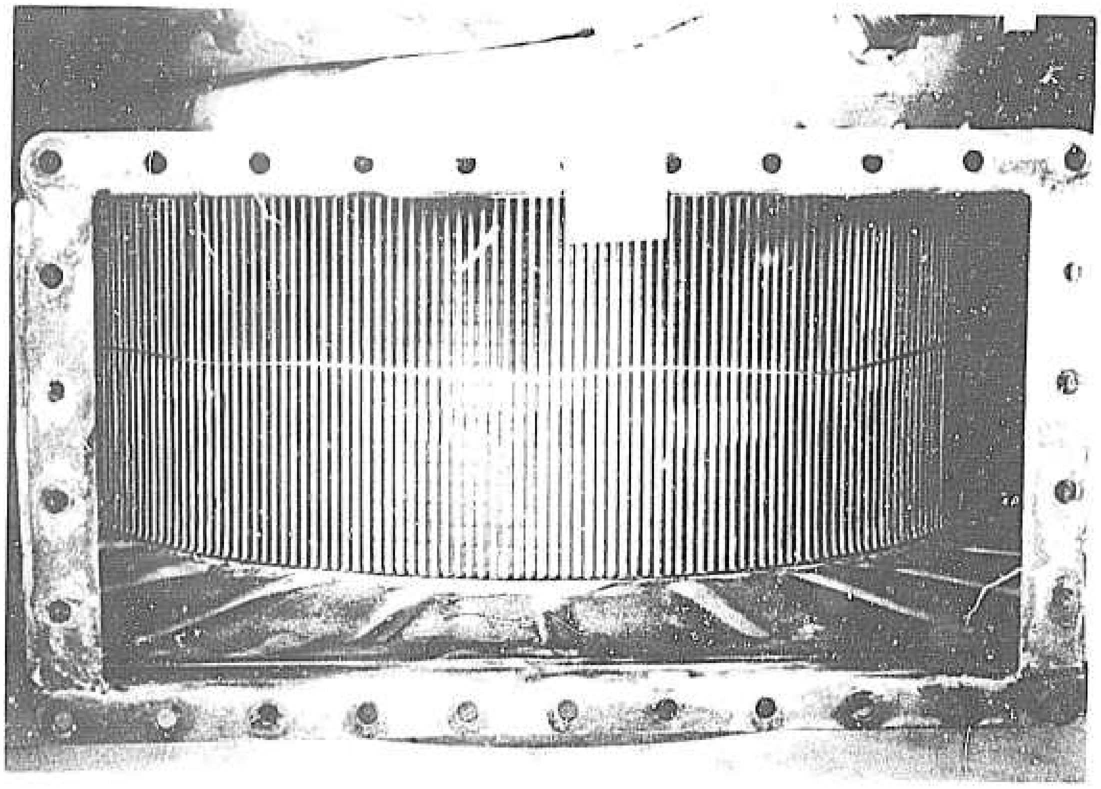


Figure 16. P/N 6858501 Regenerator (Left Side) After Dust Ingestion.

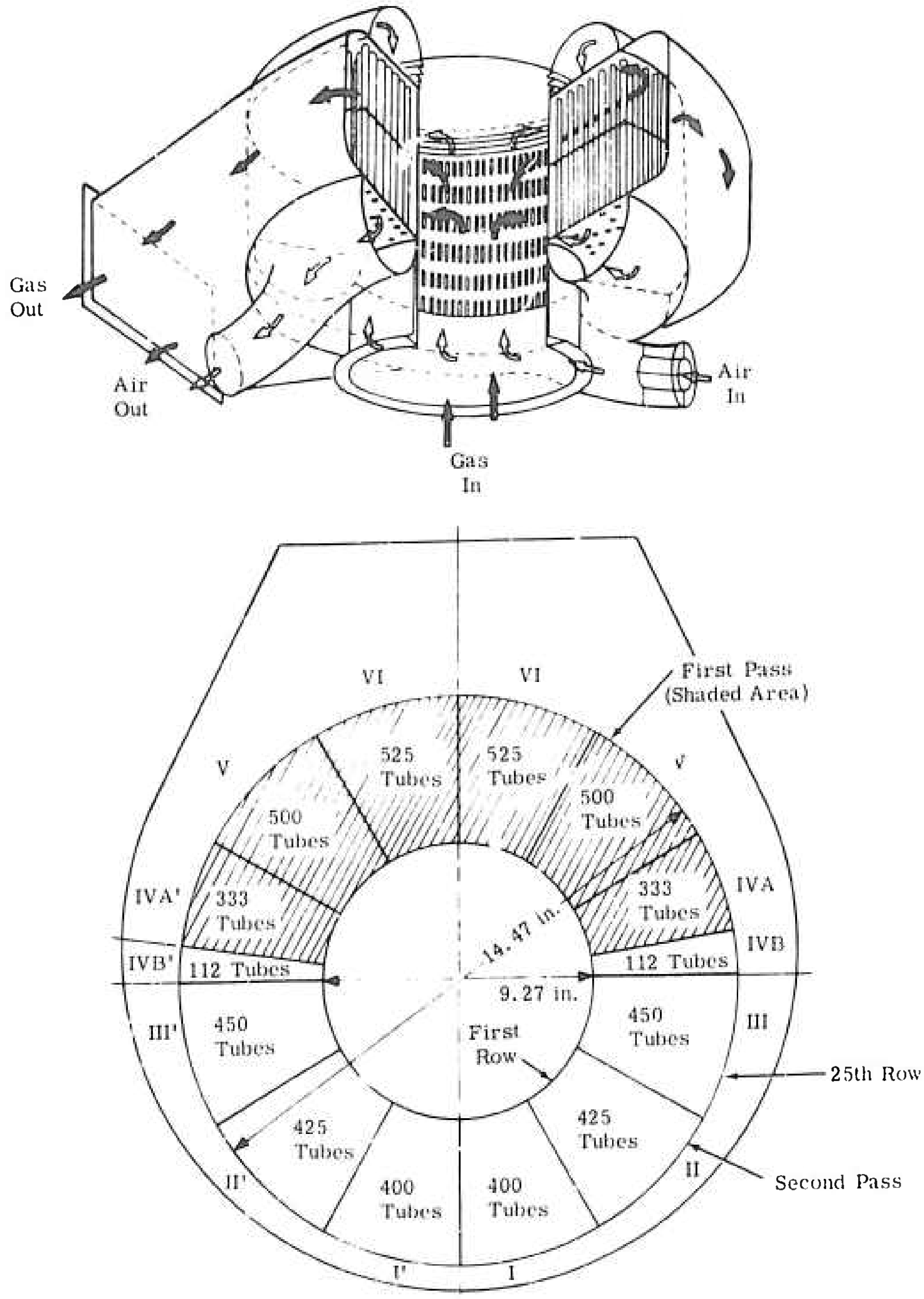
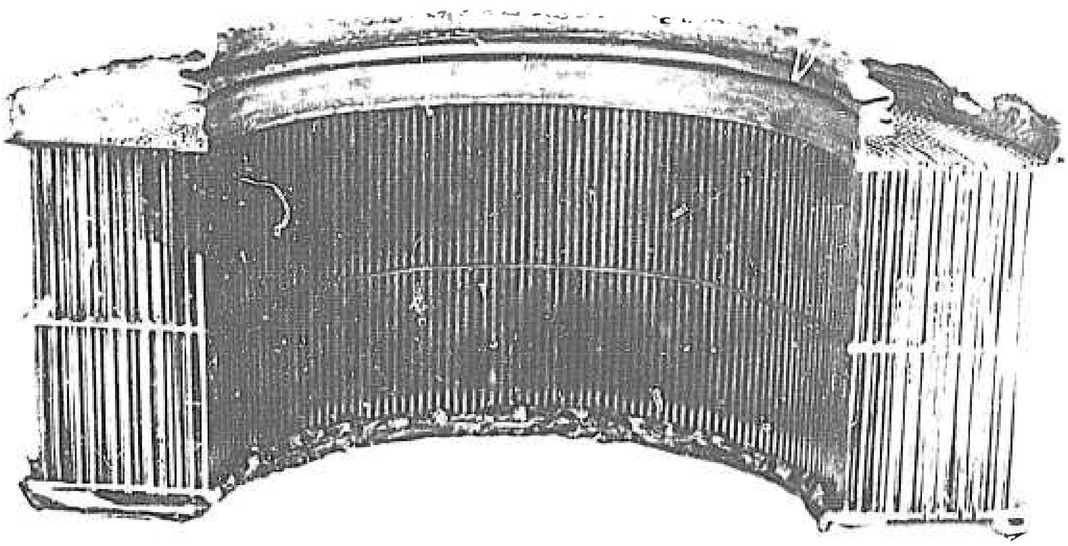
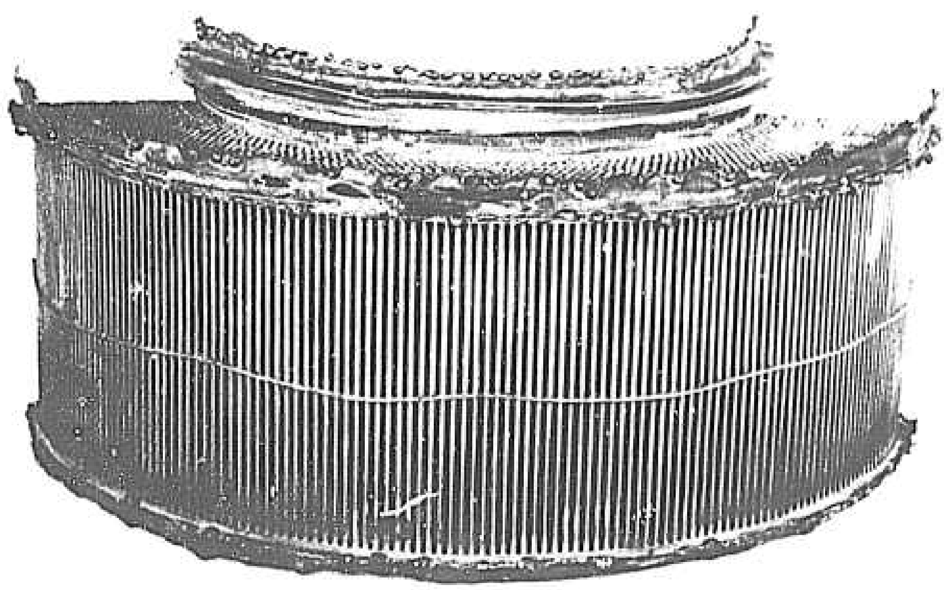


Figure 17. Regenerator Configuration.

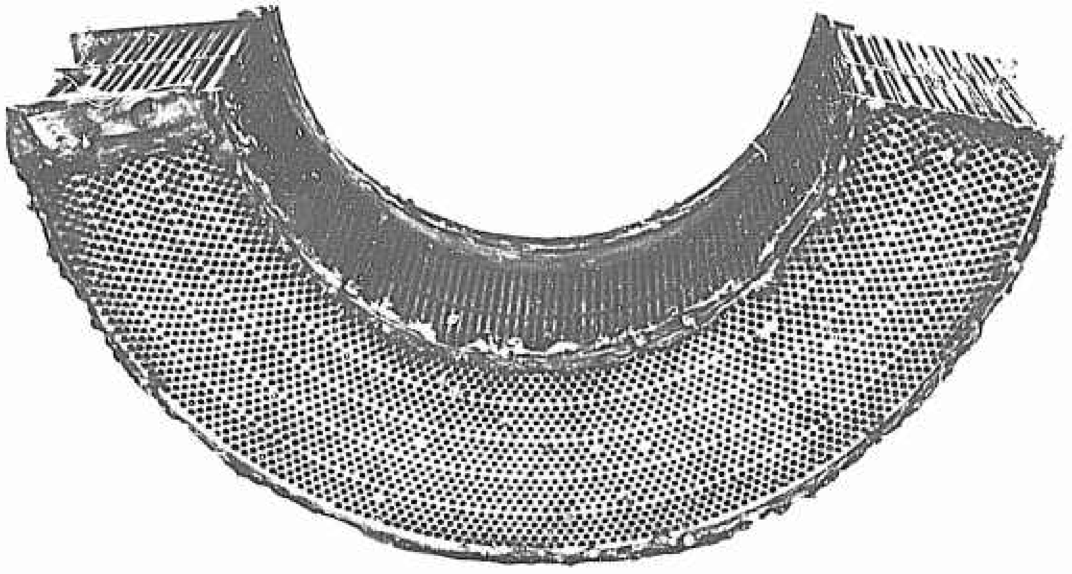


Gas Inlet - First Pass

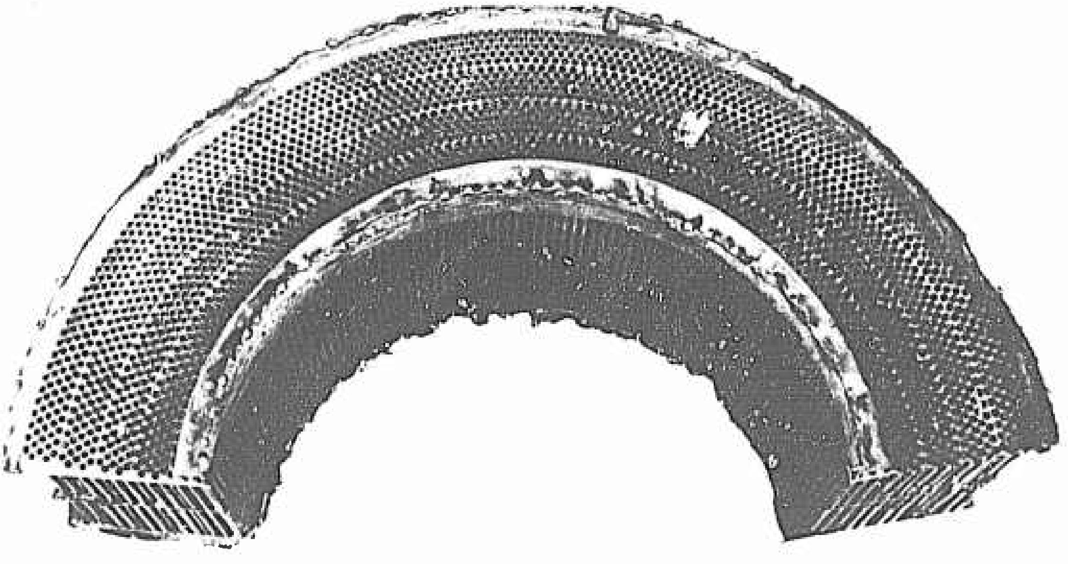


Gas Outlet – First Pass

Figure 18. Gas Side of Regenerator Core – First Pass.

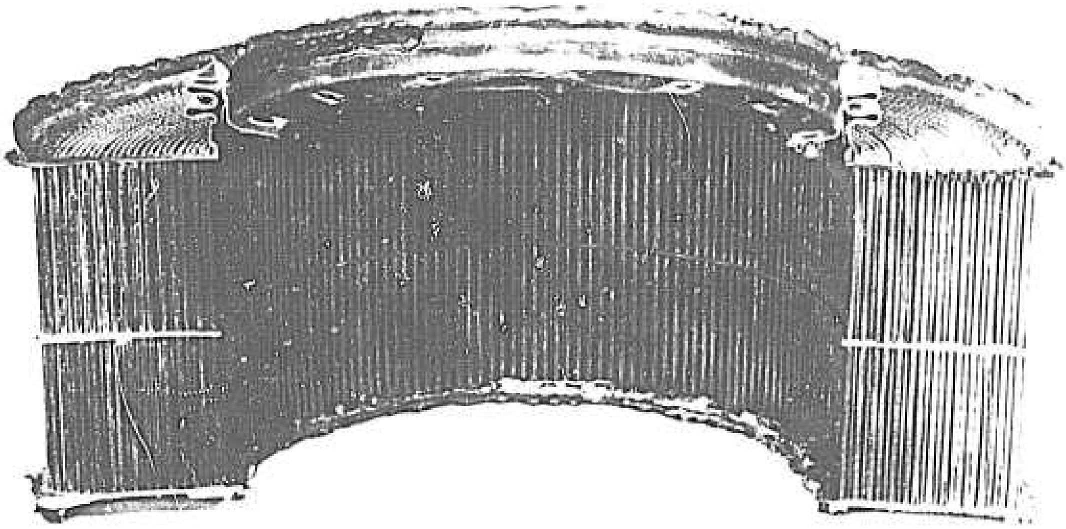


Air Inlet—First Pass

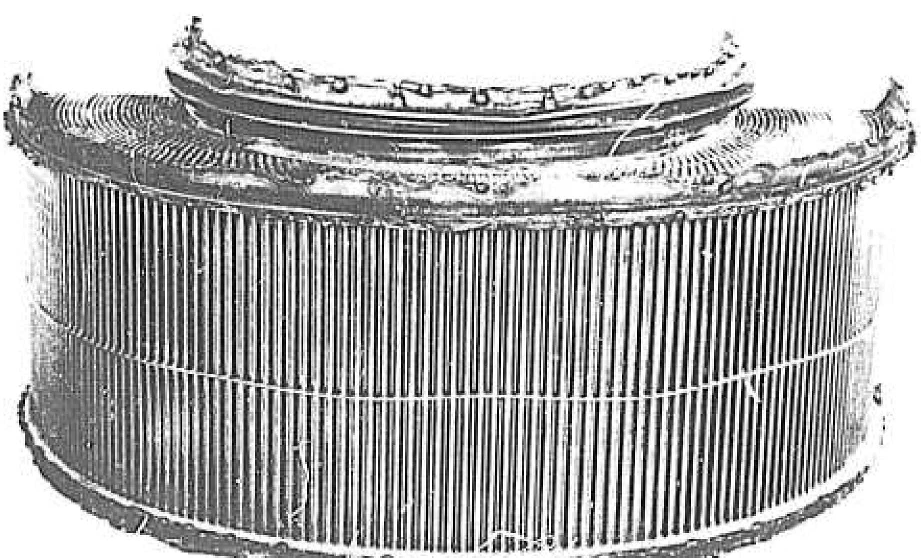


Air Outlet—First Pass

Figure 19. Air Side of Regenerator Core—First Pass.

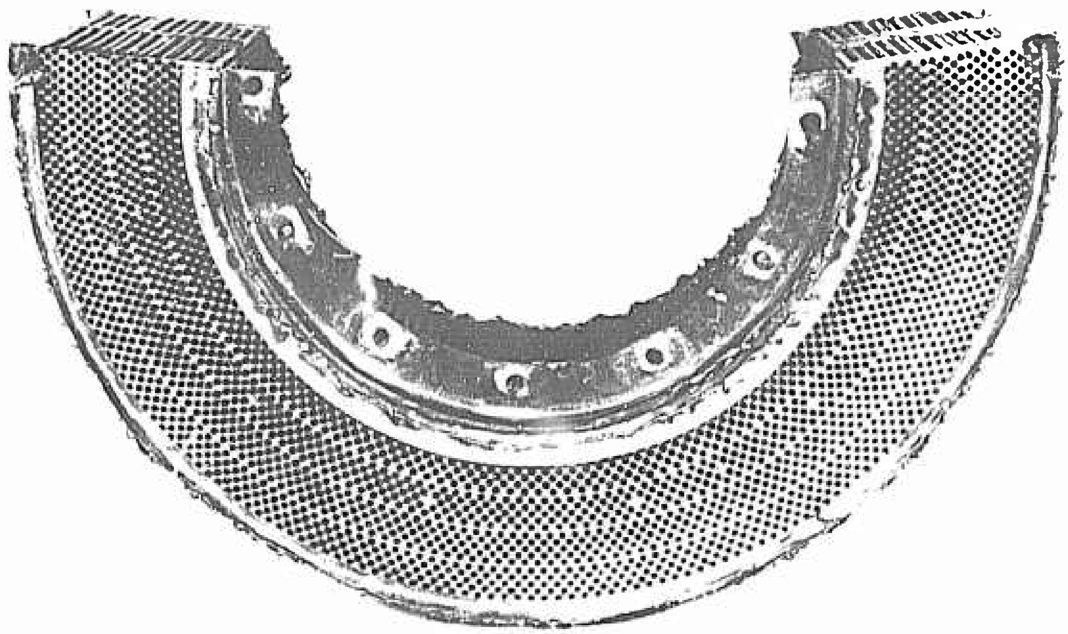


Gas Inlet—Second Pass

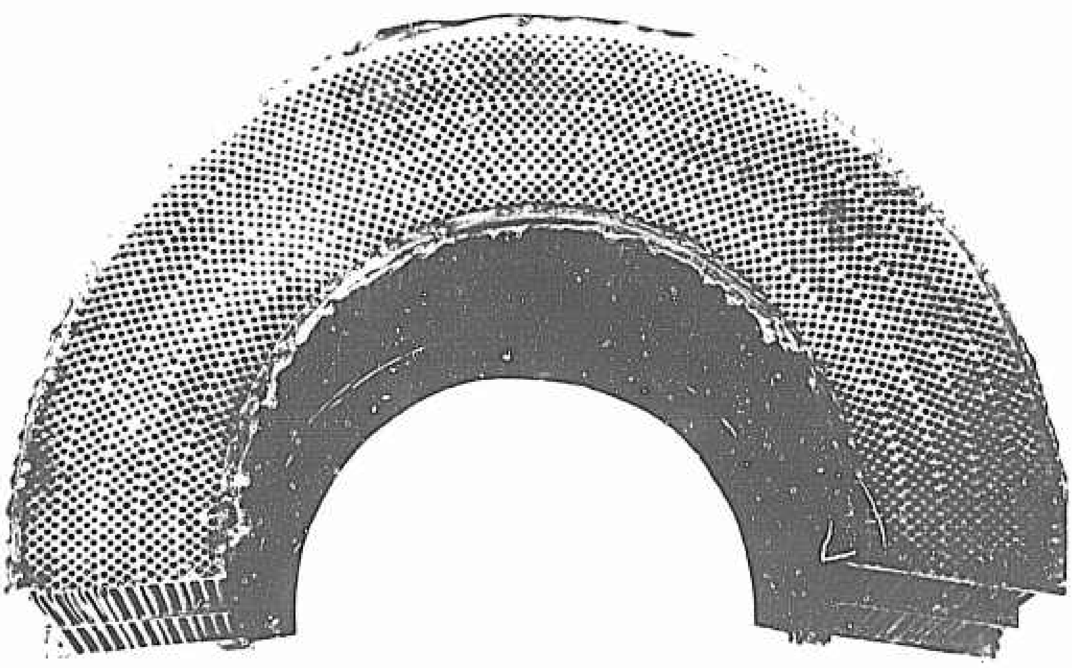


Gas Outlet—Second Pass

Figure 20. Gas Side of Regenerator Core—Second Pass.

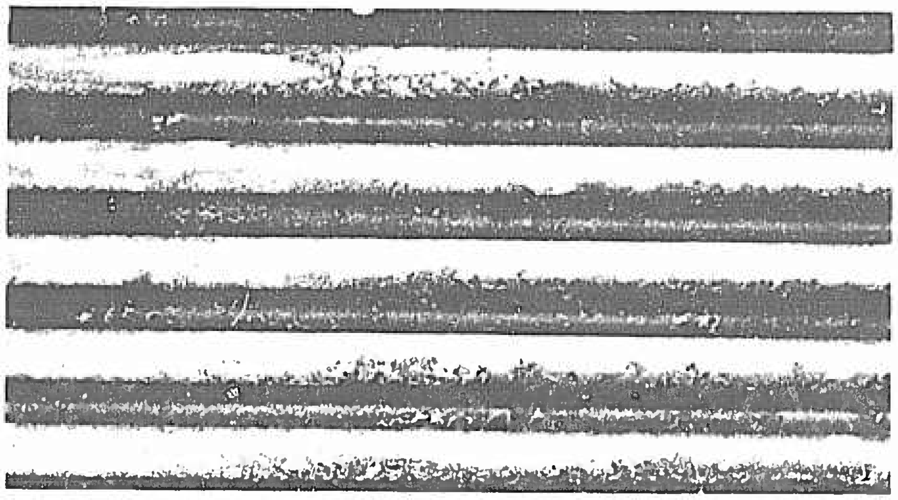


Air Inlet—Second Pass

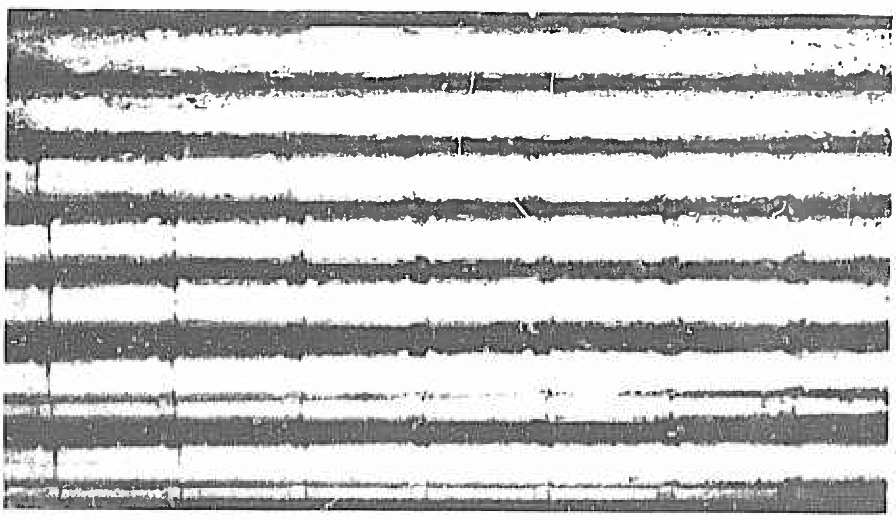


Air Outlet—Second Pass

Figure 21. Air Side of Regenerator Core—Second Pass.

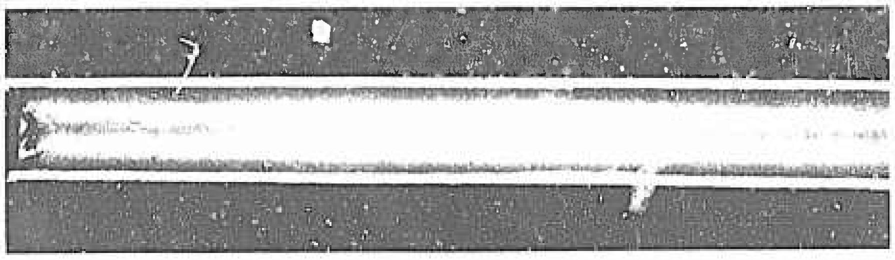


First Row of Tubes Before Cleaning

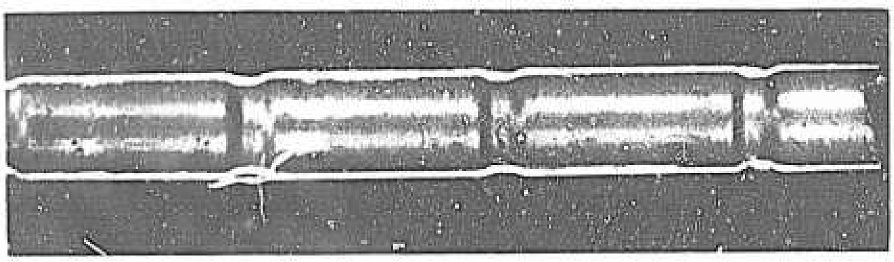


First Through Seventh Rows After Soap and Water Wash

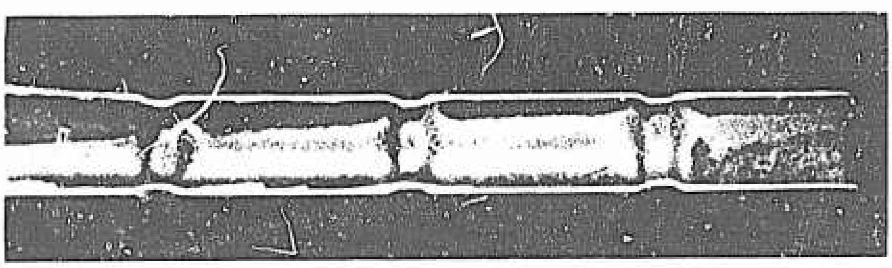
Figure 22. Outside Diameter of Gas Inlet Tubes—3X View.



Second Row—Second Pass



Third Row—Second Pass



Third Row—Second Pass
(Braze Present)

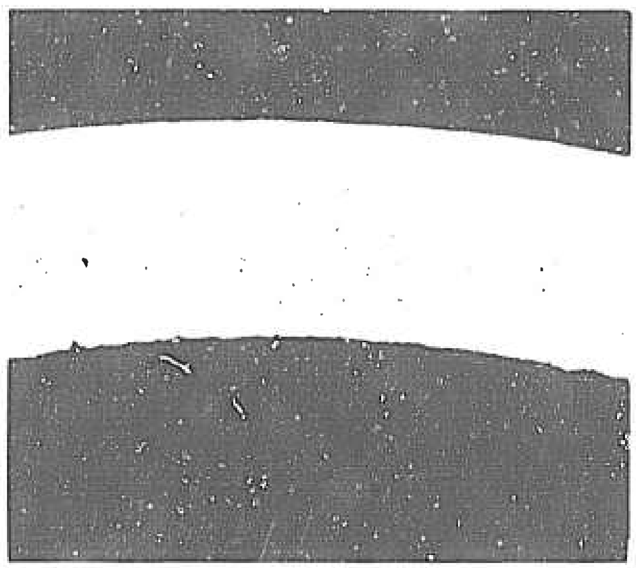
Figure 23. Inside Diameter of Gas Inlet Tubes—6X View.

Tubes were randomly selected throughout the core to check for any indications of oxidation on the outside and inside of the tubes. There was no evidence of oxidation on the outside of the tubes. The inside of the tubes showed no oxidation on those tubes without braze. The tubes with braze generally showed no oxidation except for one or two tubes in the first rows of the second pass of the core.

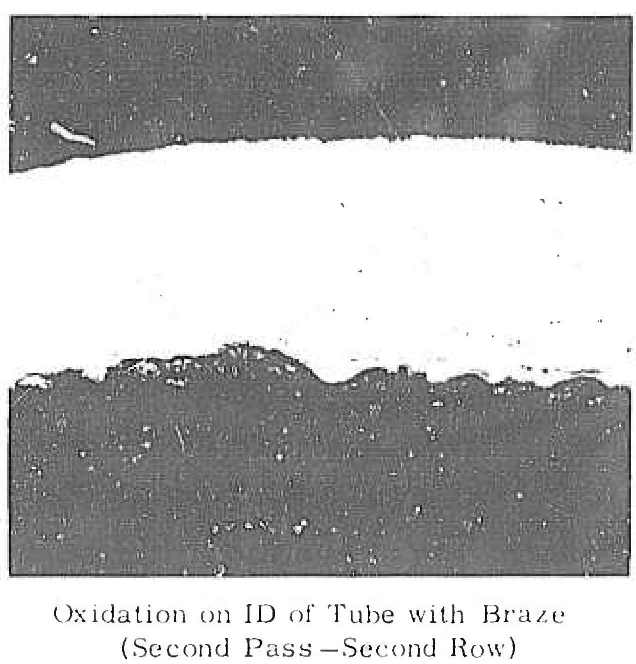
There was an indication of incipient oxidation on the surface of the braze and in the braze diffusion zone of isolated tubes in this area of the core as shown in Figure 24. The oxidation penetration was approximately 0.0005 inch. The oxidation is not considered to be serious and the photomicrographs are included primarily to document the oxidation. The tube metal temperatures in the first rows of the second pass of the core ranged from 800 to 1300°F. The steady-state metal temperatures were in the neighborhood of 800°F, with peak temperatures in the 1300°F range during transients.

Since the incipient oxidation was always associated with braze on the inside of the tubes, it is reasonable to believe that even this slight oxidation could be eliminated with the elimination of the braze.

In general, the metallurgical investigation showed that the regenerator was in excellent condition after 10 hours of dust ingestion and a total of 106 hours engine testing.



Typical Cross Section of Tube
(Second Pass – First Row)



Oxidation on ID of Tube with Braze
(Second Pass – Second Row)

Figure 24. Cross Section of Gas Inlet Tubes—200X.

SOUND SURVEY ANALYSIS

Sound surveys were conducted on the Allison Plant 10 flight facility apron as parasitic tests during the performance evaluation of the T63 engine in the Hughes YOH-6A helicopter. Data were obtained from both the regenerative (250-E3) and the standard (T63-A-5) engines so that the effect of the regenerator on engine noise could be determined.

Changes in the exhaust nozzle required by installation of the regenerator are shown in Figures 25 through 27.

Identical test procedures were used in both cases to provide uniform data for comparison purposes. The helicopter was hovered, in ground effect, while noise was recorded. The microphone positions were in 10-degree increments from zero (front) to 180 degrees around the left side of the helicopter on a 100-foot radius from the main rotor mast.

Data reduction was accomplished by playing the noise recordings back through one-third octave filters. The filtered level was digitized so that the microphone and recording system corrections and all computations could be made by computer. PNdB conversions were made using the tables and method given in SAE ARP 865. Sound power computations followed the classical method as shown in Figure 28. Sound pressure level symmetry was assumed in determining sound power.

Noise received by the microphone is a composite from engine and non-engine sources. The most important nonengine noise sources are the helicopter main and tail rotors. The major portion of rotor noise is easily identified because of its direct relation to rotor speed and number of rotor blades. Table VII presents a description of the rotor system and the frequencies at which rotor noise will appear.

Analysis of the noise data proceeded with two objectives in mind.

- Determine the effect of the regenerator on engine noise.
- Evaluate engine and rotor noise in terms of human environment.

The effect of the regenerator on engine noise was analyzed in terms of sound power to avoid the possible confusion arising from changes in sound direction associated with the installation of the regenerator. One-third octave band sound power levels for the 191 horsepower (hover in ground effect at maximum gross weight) and 29 (idle) horsepower conditions are shown in Figures 29 and 30. At 191 horsepower, the dominance of rotor noise clearly extends to the 400-Hz band. Above 400 Hz, the effect of the

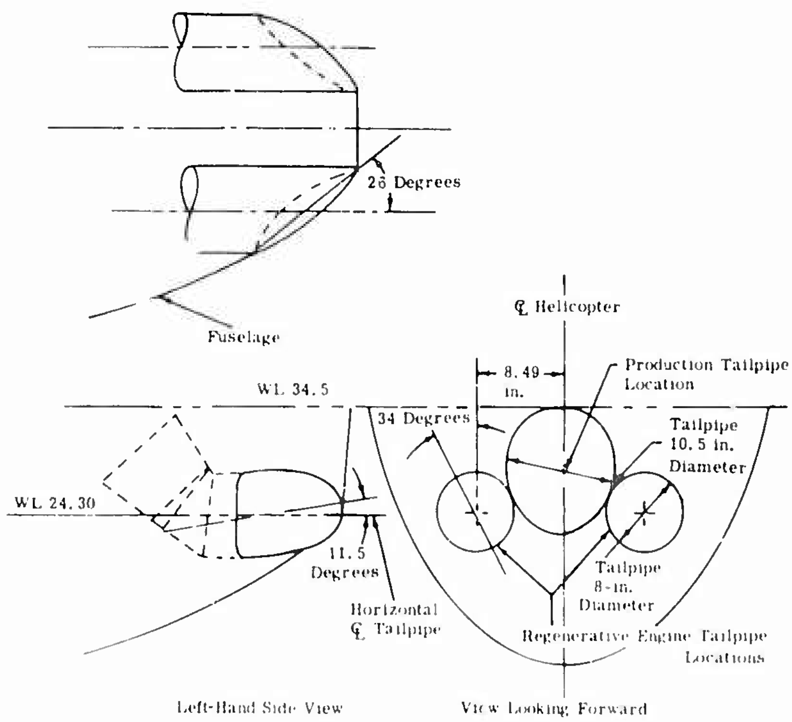


Figure 25. Engine Exhaust Nozzles for Regenerative and Nonregenerative Engines.

Figure 26. YOH-6A Helicopter With T63-A-5A (Nonregenerative) Engine.

Figure 27. YOH-6A Helicopter With 250-E3 (Regenerative) Engine.

TABLE VII. ROTOR PASSAGE FREQUENCIES

Rotor	Reduction Ratio	No. of Blades	Power Turbine Speed (RPM)	Rotor Speed (Hz)	Rotor Blade Passage (Hz) X1	X2	X3	X4
Main	0.0134	4	35,000	7.8	31.2	62.4	93.6	124.8
			25,900	5.6	23.1	46.2	69.3	92.4
			25,200	5.1	20.4	40.8	61.2	81.6
Tail	0.0862	2	35,000	50.3	100.6	201.2	301.8	402.4
			25,900	37.2	74.4	148.8	223.2	297.6
			25,200	36.2	72.4	144.8	217.2	289.6

$$W = \frac{\pi r^2}{\rho c} \int_0^{180} p_{avg}^2 \sin \beta d\beta$$

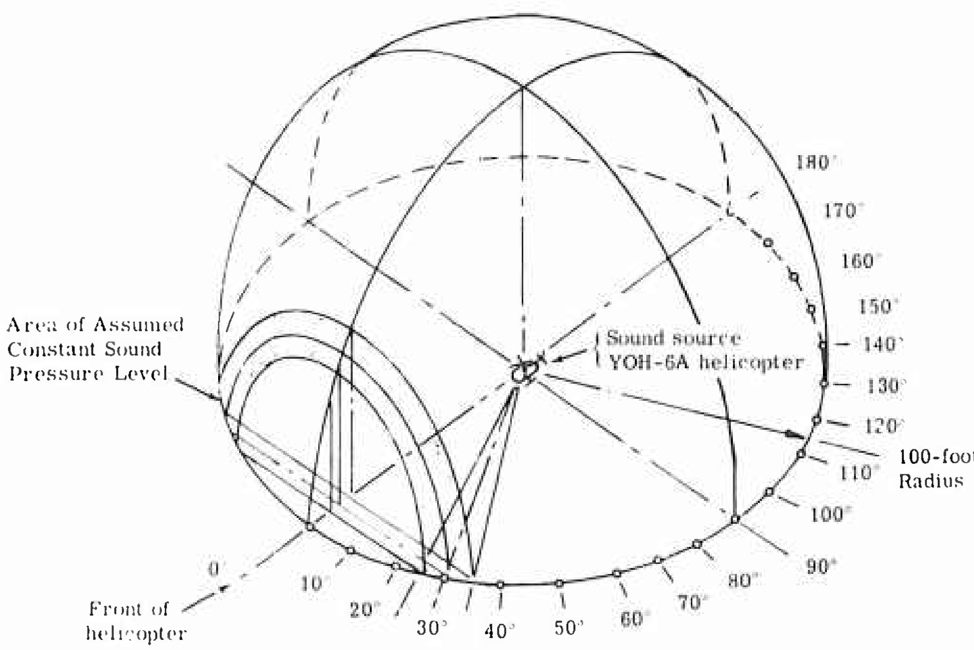
where, W = acoustic power—watts
r = hemispherical radius—meters
ρc = characteristic impedance of air = 410 newtons—second/meter^3
p = sound pressure—newton/meter^2
β = azimuth angle—degrees

Since measurements were taken every 10°, the sound pressure has been assumed to be constant ±5° from the angle of measurement and thus:

$$W = \frac{\pi r^2}{\rho c} \sum_0^{180} p_1^2 (\cos \beta_1 - \cos \beta_2)$$

where: β_1 = measurement azimuth angle -5°
β_2 = measurement azimuth angle +5°

Sound power level (PWL) = $10 \log \frac{W}{10^{-12}}$ dbp



Sound Pressure Measurement Locations—Azimuth Angle (β)

Figure 28. Sound Power Calculation Method.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

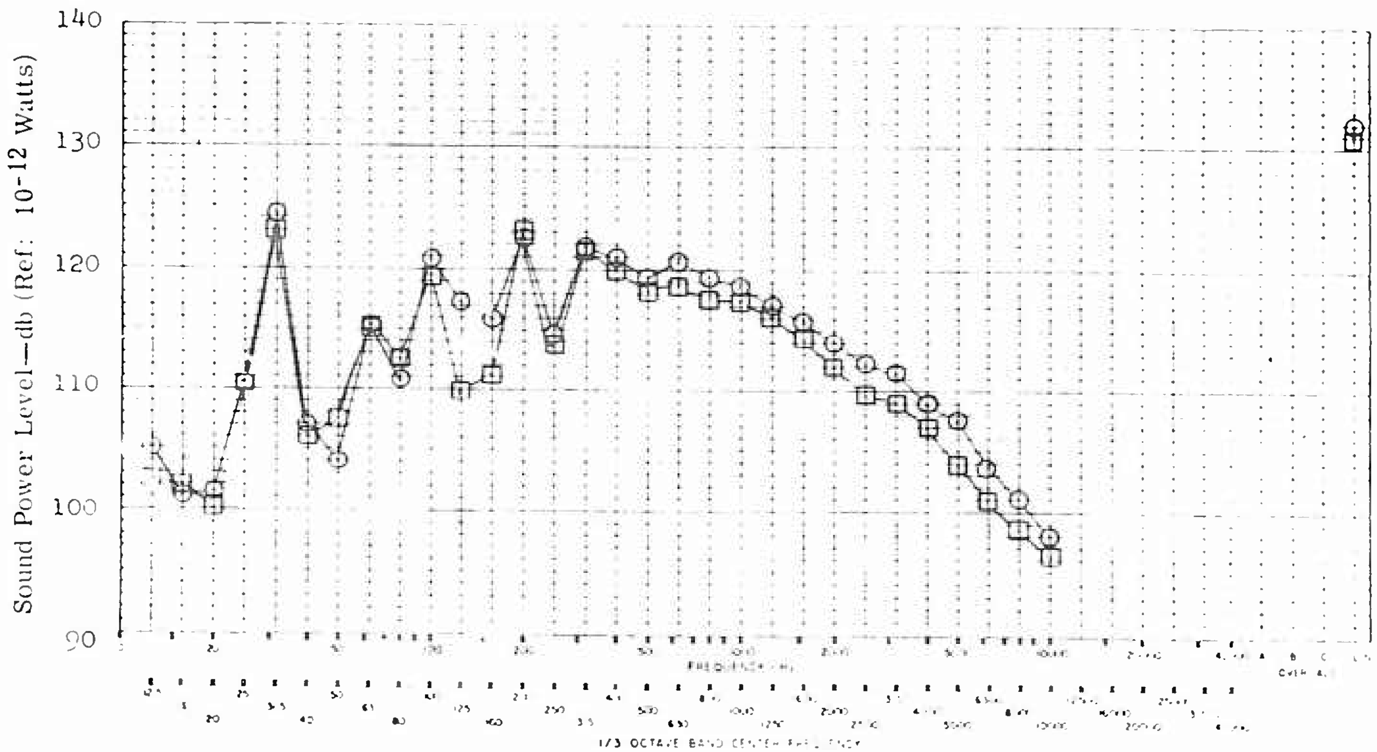


Figure 29. One-third Octave Band Sound Power Levels at 191 HP.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31, 183	25, 200	29
□—□	250-E3 (Regenerative)	21, 980	25, 900	29

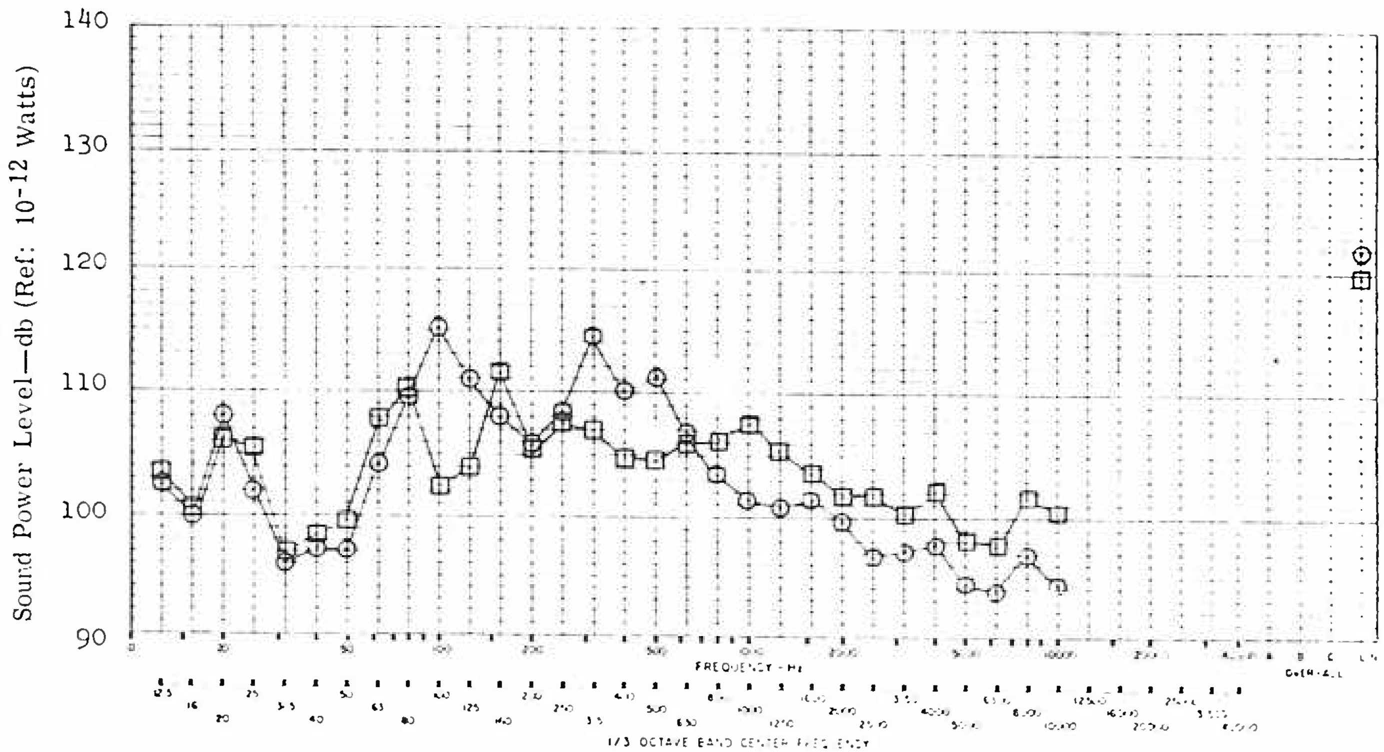


Figure 30. One-third Octave Band Sound Power Level at 29 HP.

regenerator is clearly revealed as a two- to three-decibel reduction in power level. Below 400 Hz, although partially obscured by the rotor noise, a reduction in exhaust nozzle noise is evident in the 100-to 160-Hz bands. Even though the regenerator did produce measurable noise reduction, it is doubtful that the reduction would be noticed by a casual observer since the two- to three-decibel high-frequency reduction is near the threshold of detection (15 to 20% noise change) and the change in exhaust noise would be masked by the unchanging rotor noise.

At idle, the comparison is confusing. Definite noise reductions occurred in the exhaust noise bands (80 to 160 Hz) and in the 315-to-500 Hz bands. The source for the 315-to-500 Hz bands is not known. Above the 630-Hz band, noise actually increased with the regenerator installed. The tendency to peak in the 4000- and 8000-Hz bands may point to an explanation for this unexpected result. The peaking tendency points to the presence of discrete tones in these bands. The tones appear in the same bands for the regenerative and the nonregenerative configurations, indicating that the source is related to speed variation. Since the ratio of observed gas producer speeds (31,183 to 21,980 rpm) is greater than the ratio of band center frequencies, the tones must be associated with power turbine speed. The engine has only one source, the power takeoff drive gear, which would contribute to the 4000- and 8000-Hz bands. Details of the helicopter's main reduction gearbox train are not known, so possible contributions from this source cannot be identified. Since the noise above the 630-Hz band is linked to power turbine speeds, it appears that at low horsepower, this portion of the spectrum is dominated by gearbox noise from the engine or the helicopter or both. The higher levels observed with the regenerator installed could be the result of the higher power turbine speed during this testing.

Figure 31 presents the previously discussed noise reductions in direct form as the difference for each one-third octave band between the nonregenerative and regenerative configurations.

Perceived noise (PNdB) for the 191-horsepower and 29-horsepower conditions is shown in Figures 32 and 33 in polar form to illustrate the variation in PNdB around the helicopter. Changes in perceived noise between the regenerative and nonregenerative engine follow the observations made concerning sound power. At 191 horsepower, the regenerative configuration is quieter by 1 to 3 PNdB from 20 degrees to 170 degrees around the helicopter. At 29 horsepower, the regenerative configuration shows an increase of 1 to 4 PNdB in the forward arc (0 to 110 degrees), which was due to variations in rotor speed.

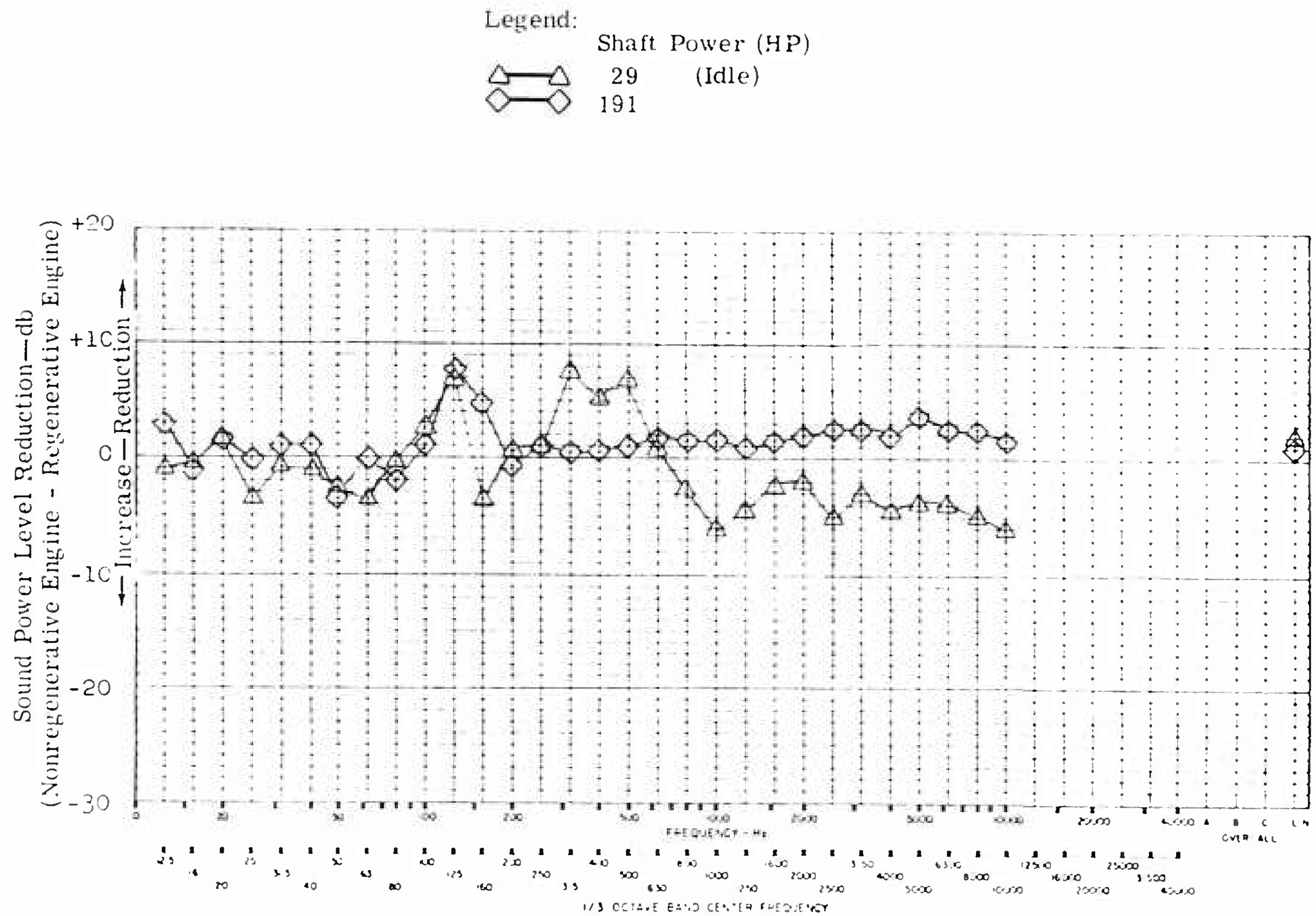


Figure 31. One-third Octave Band Sound Power Level Reduction.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

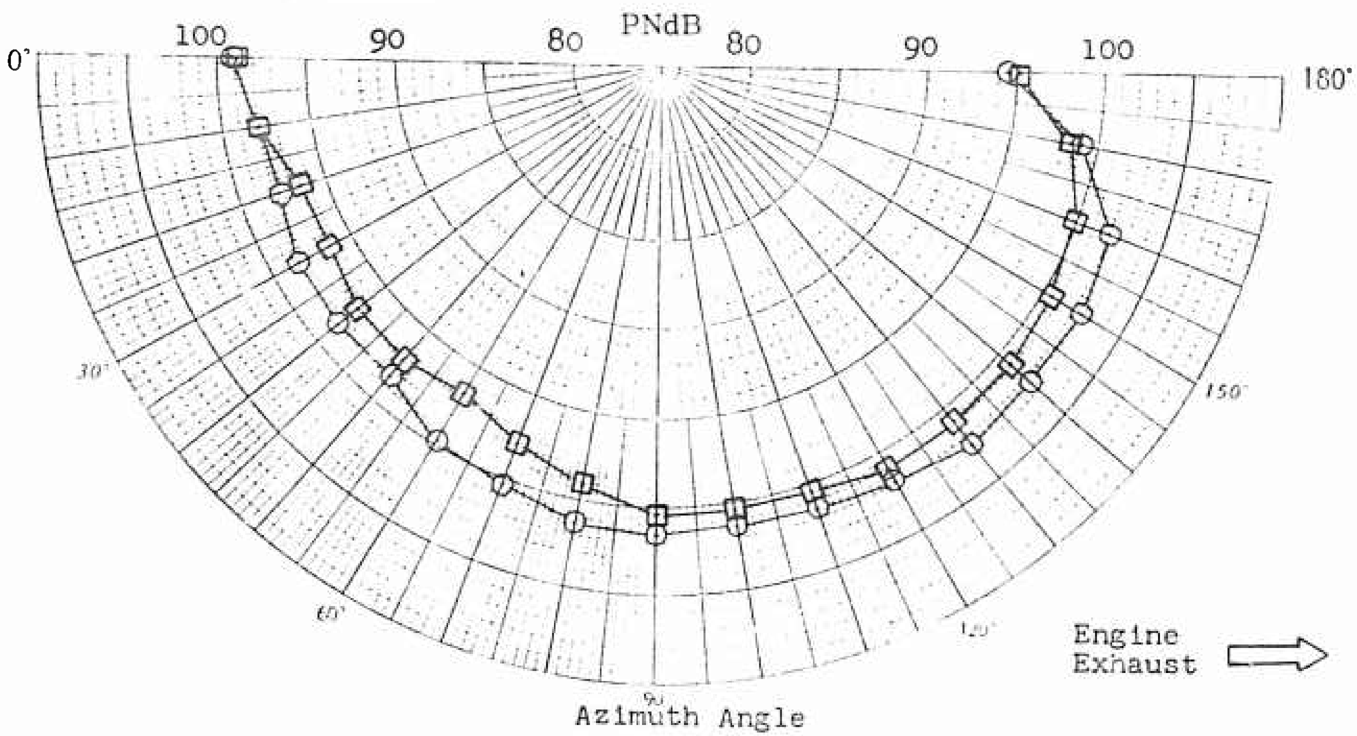


Figure 32. 100-Foot Distance Perceived Noise Level at 191 HP—PNdB.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

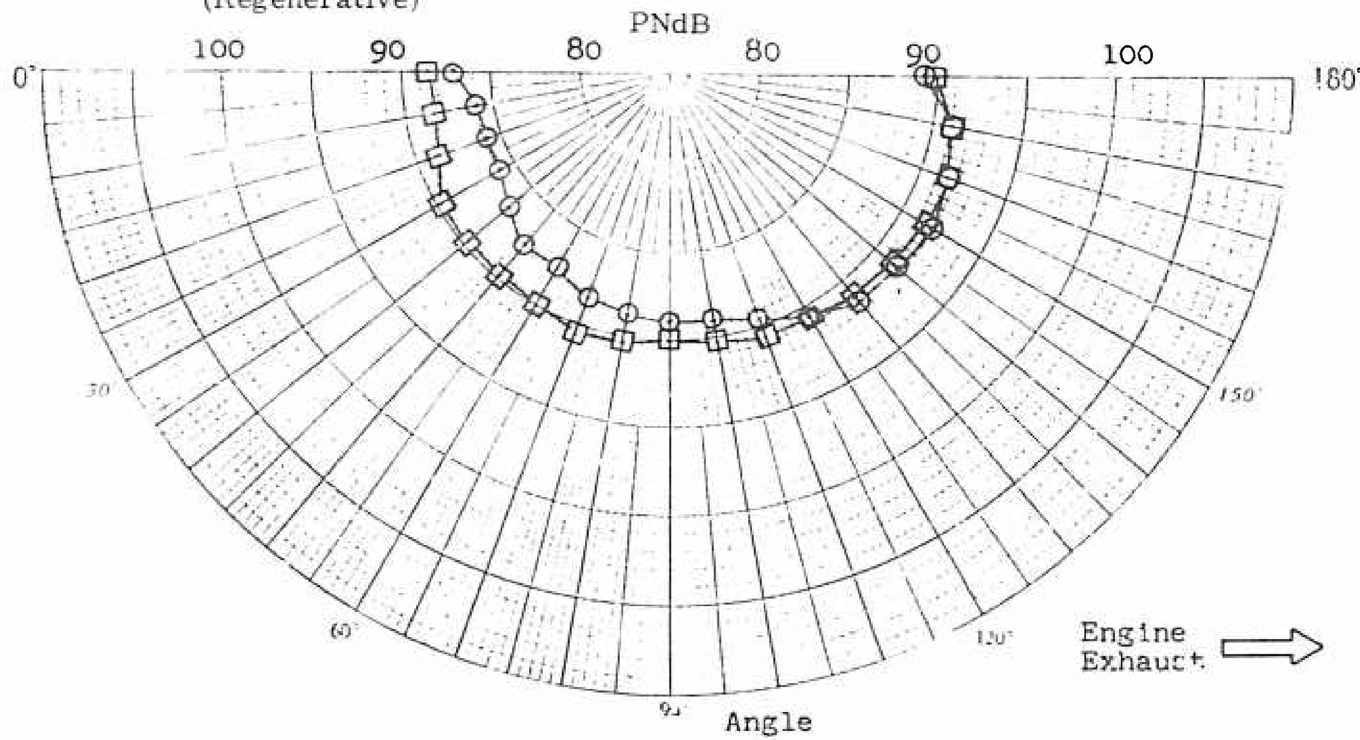


Figure 33. 100-Foot Distance Perceived Noise Level at 29 HP—PNdB.

The maximum levels of perceived noise 101.0 and 102.5 PNdB for the regenerative and nonregenerative configurations fall within the range of commonly observed but undesirably high airport noise. These levels will vary with changes in horsepower and/or distance. At distances or altitudes of about 1000 feet, the maximum level should be 80 to 85 PNdB or less which is generally acceptable by today's standards.

Figure 34 shows the changes in perceived noise between the nonregenerative and regenerative configurations for both 191 and 29 horsepower.

The noise emitted from the helicopter was evaluated for possible hearing damage risk using MIL-A-8806 Revision B (proposed) as a guide. Figure 35 shows a comparison of the criteria and the maximum observed band levels. The band levels were adjusted to account for the change in band width prior to plotting them in Figure 35.

The maximum one-third octave band levels observed at 100 feet are shown in Table VIII and do not indicate any significant damage risk for exposures of about 1 hour or less. However, crew members working within 25 feet of the helicopter should be provided with ear protection if their exposure will exceed 15 minutes.

The measured sound pressure levels used to compute sound power and perceived noise levels are shown in Figures 36 through 57.

TABLE VIII. MAXIMUM OBSERVED ONE-THIRD OCTAVE BAND SOUND PRESSURE LEVELS AT 100 FEET

One-Third Octave Band Center Frequency (Hz)	Sound Pressure Level (db)
16	75
31.5	88
63	82
125	91
250	90
500	91
1000	88
2000	83
4000	79
8000	71

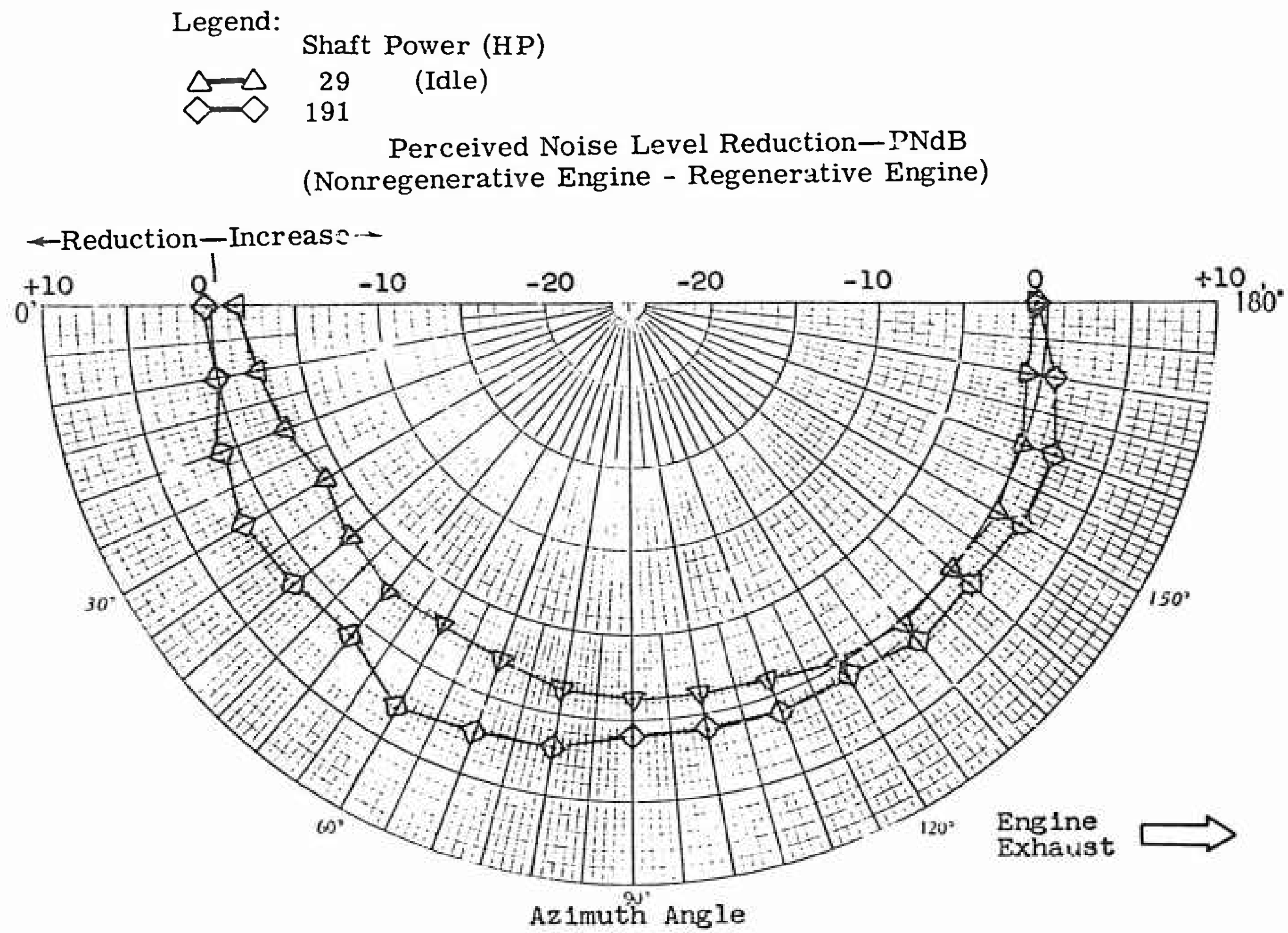


Figure 34. 100-Foot Distance Perceived Noise Level Reduction—PNdB.

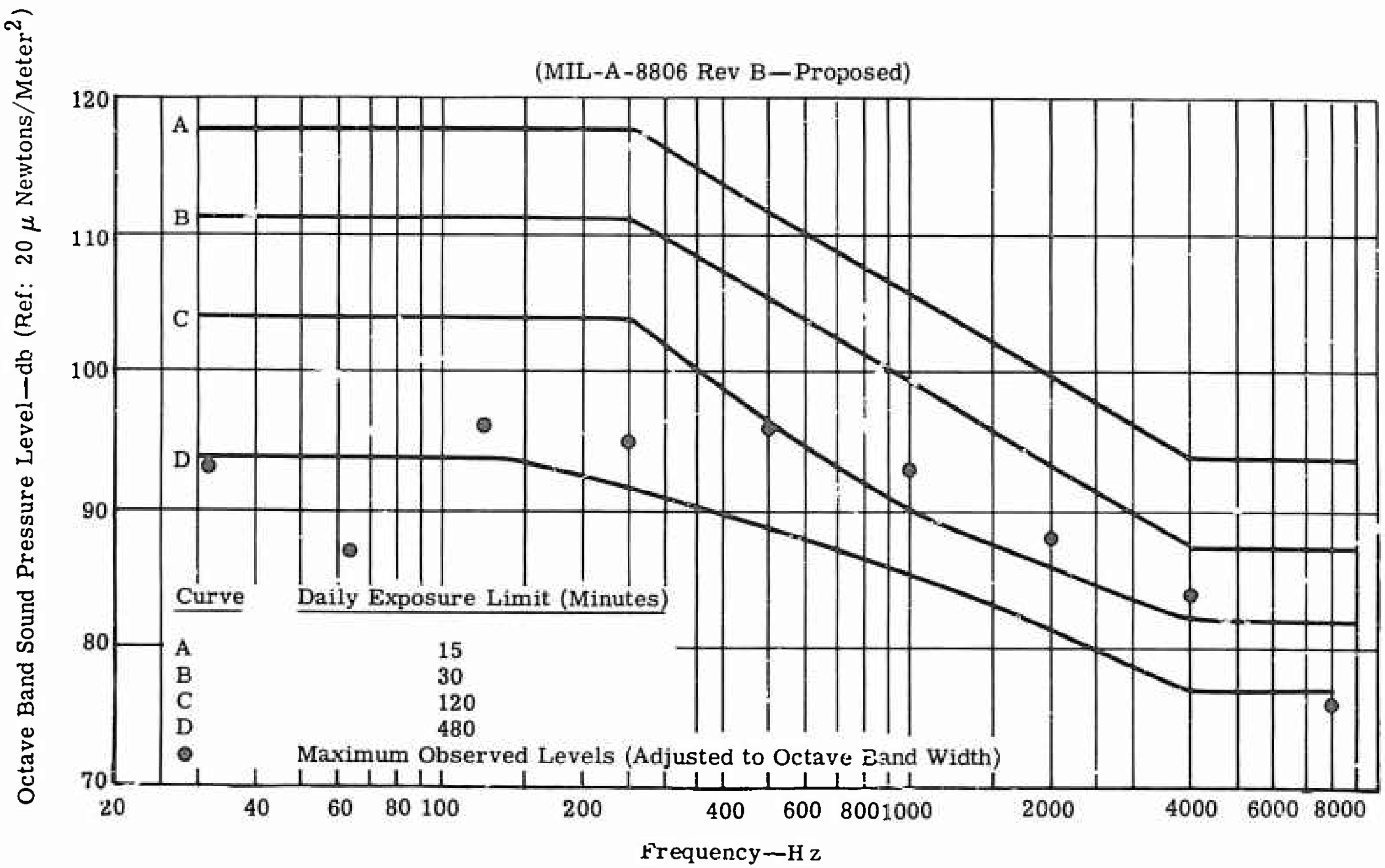


Figure 35. Damage Risk Criteria.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	46, 008	35, 000	191
□—□	250-E3 (Regenerative)	45, 906	35, 000	191

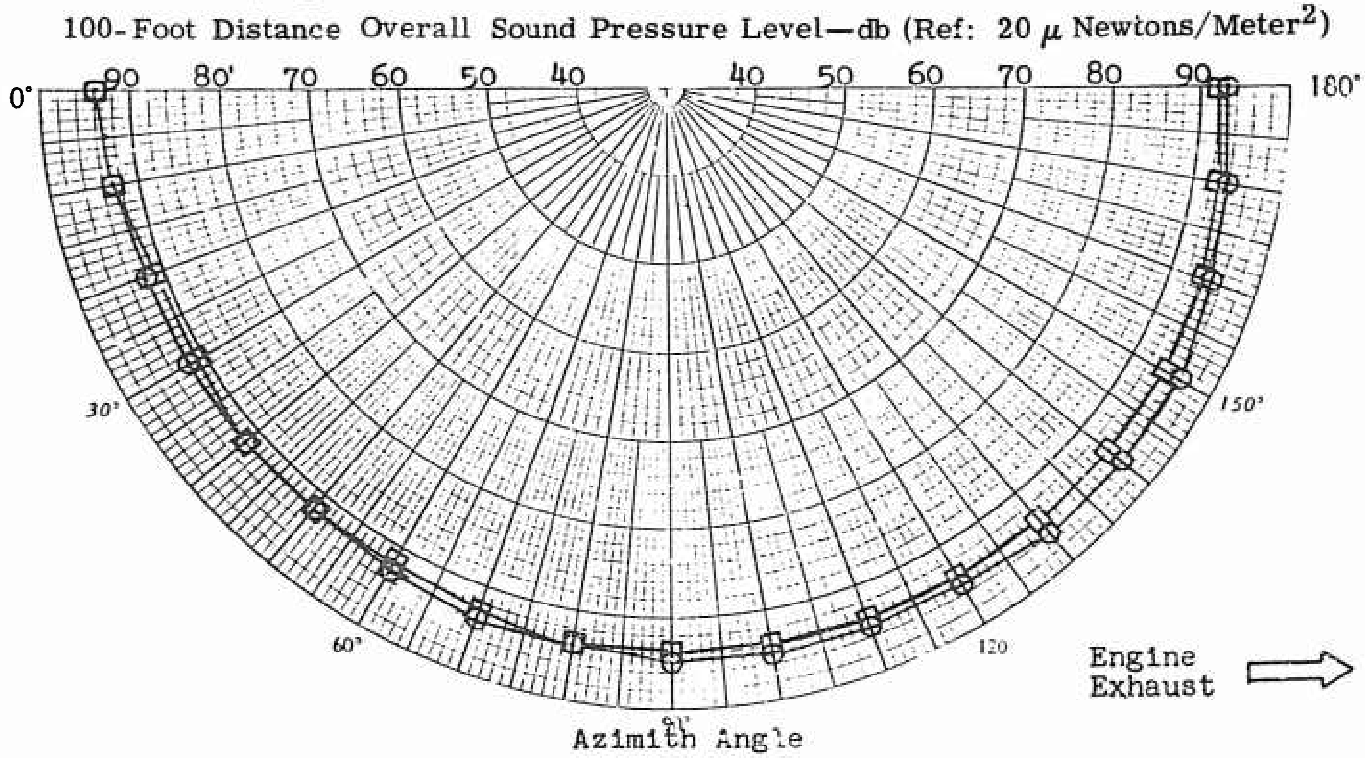


Figure 36. Sound Pressure Level at 191 HP—Overall.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

100-Foot Distance Octave Band Sound Pressure Level—db (Ref: 20 μ Newtons/Meter^2)

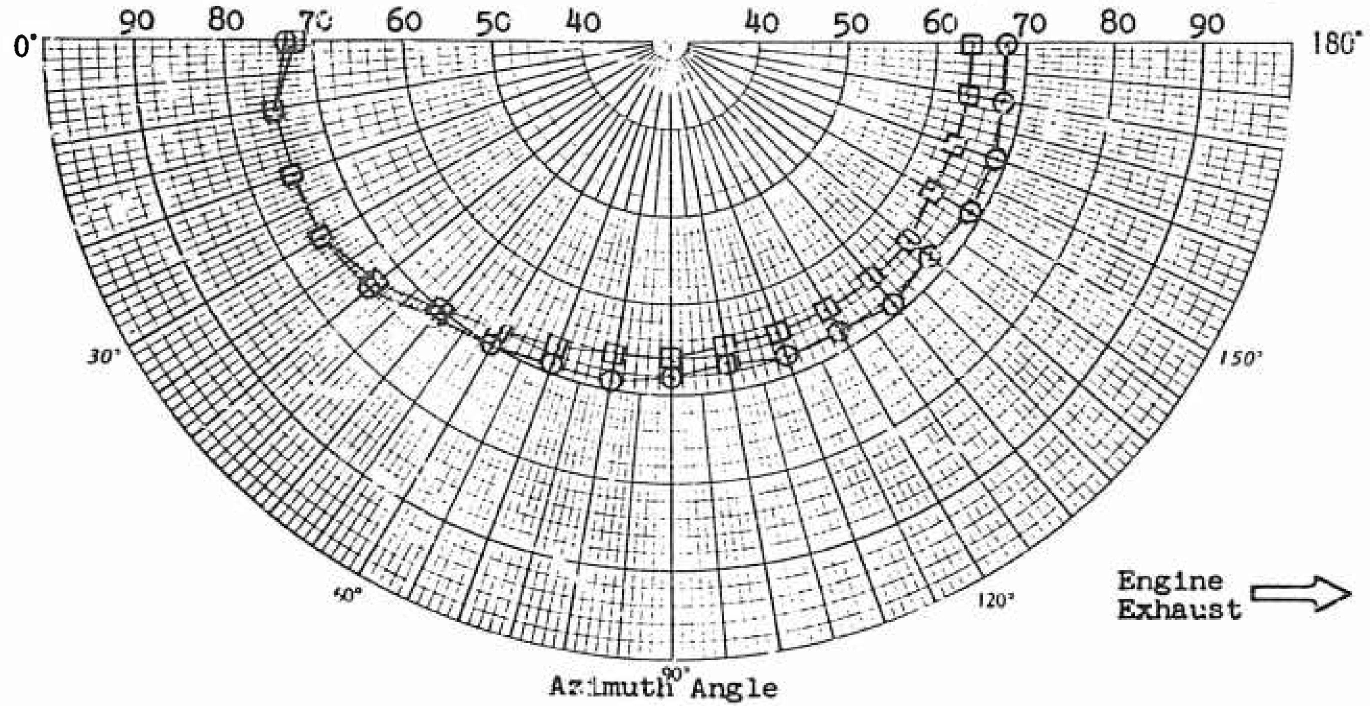


Figure 37. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 16 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46, 008	35, 000	191
□—□	250-E3 (Regenerative)	45, 306	35, 000	191

100-Foot Distance Octave Band Sound Pressure Level—db (Ref: 20 μ Newtons/Meter^2)

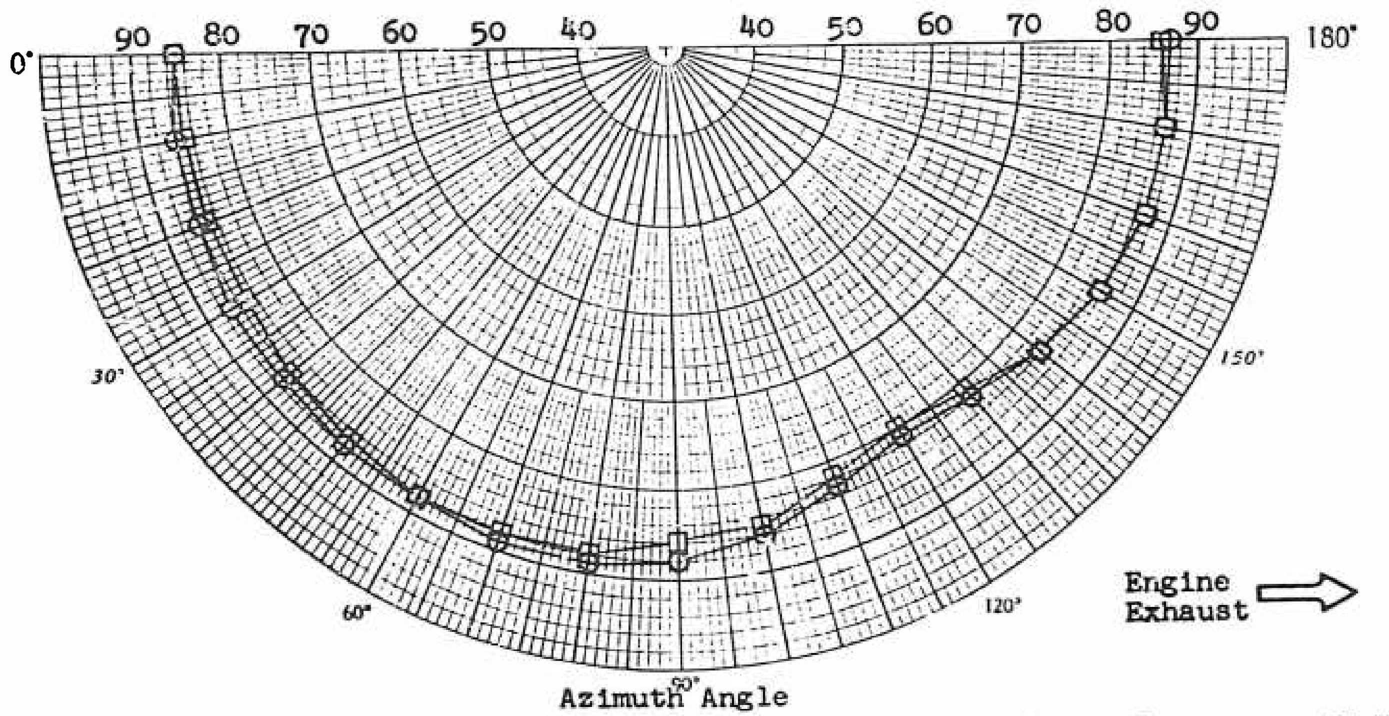


Figure 38. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 31.5 Hz.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46, 008	35, 000	191
□—□	250-E3 (Regenerative)	45, 906	35, 000	191

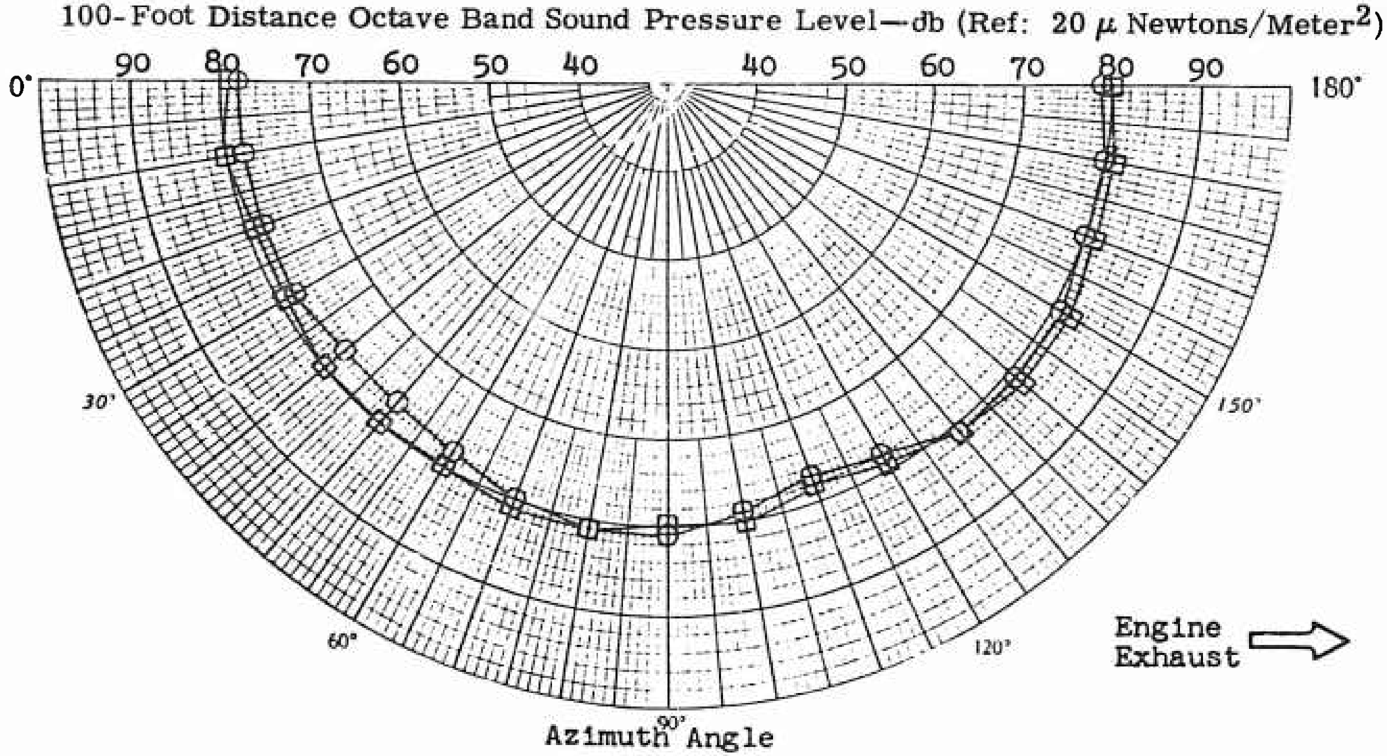


Figure 39. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 63 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46, 008	35, 000	191
□—□	250-E3 (Regenerative)	45, 906	35, 000	191

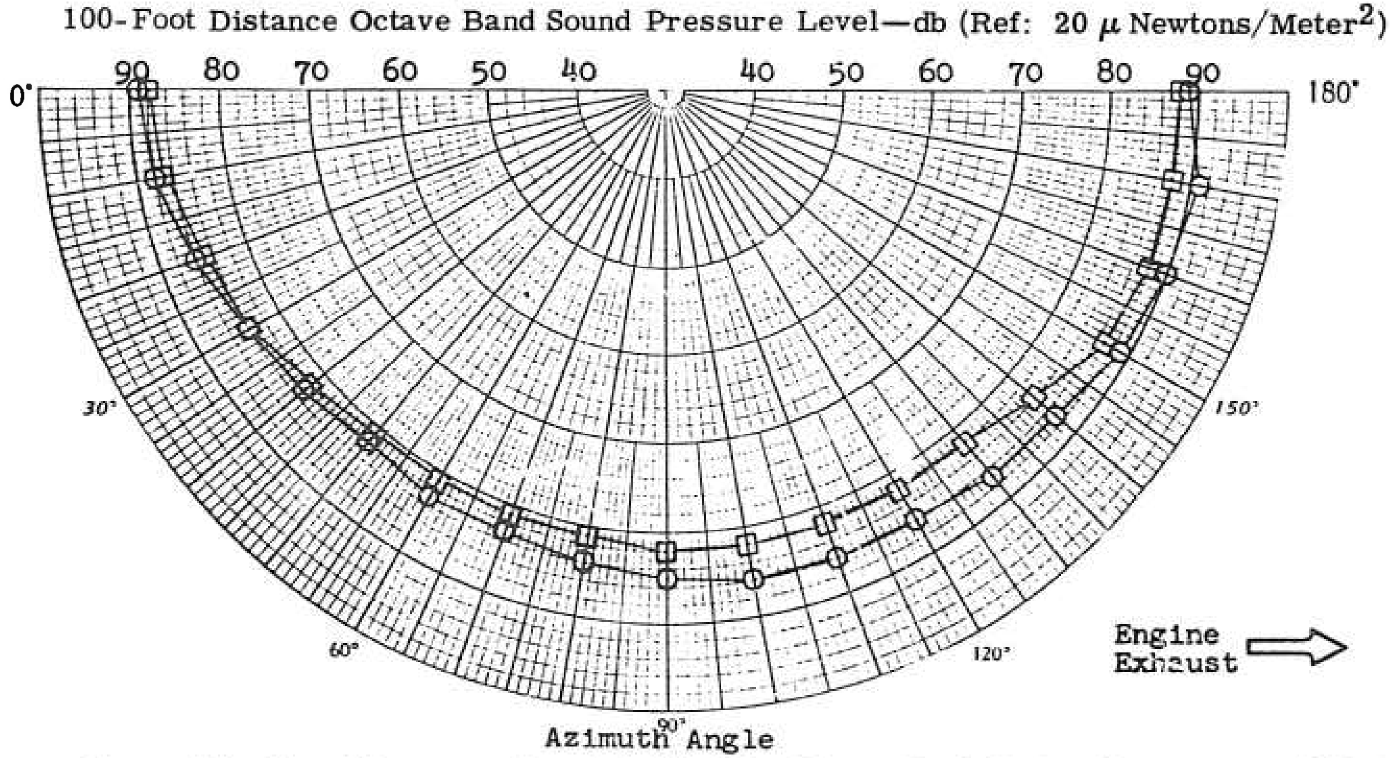


Figure 40. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 125 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
o—o	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

100-Foot Distance Octave Band Sound Pressure Level—db (Ref: 20 μ Newtons/Meter^2)

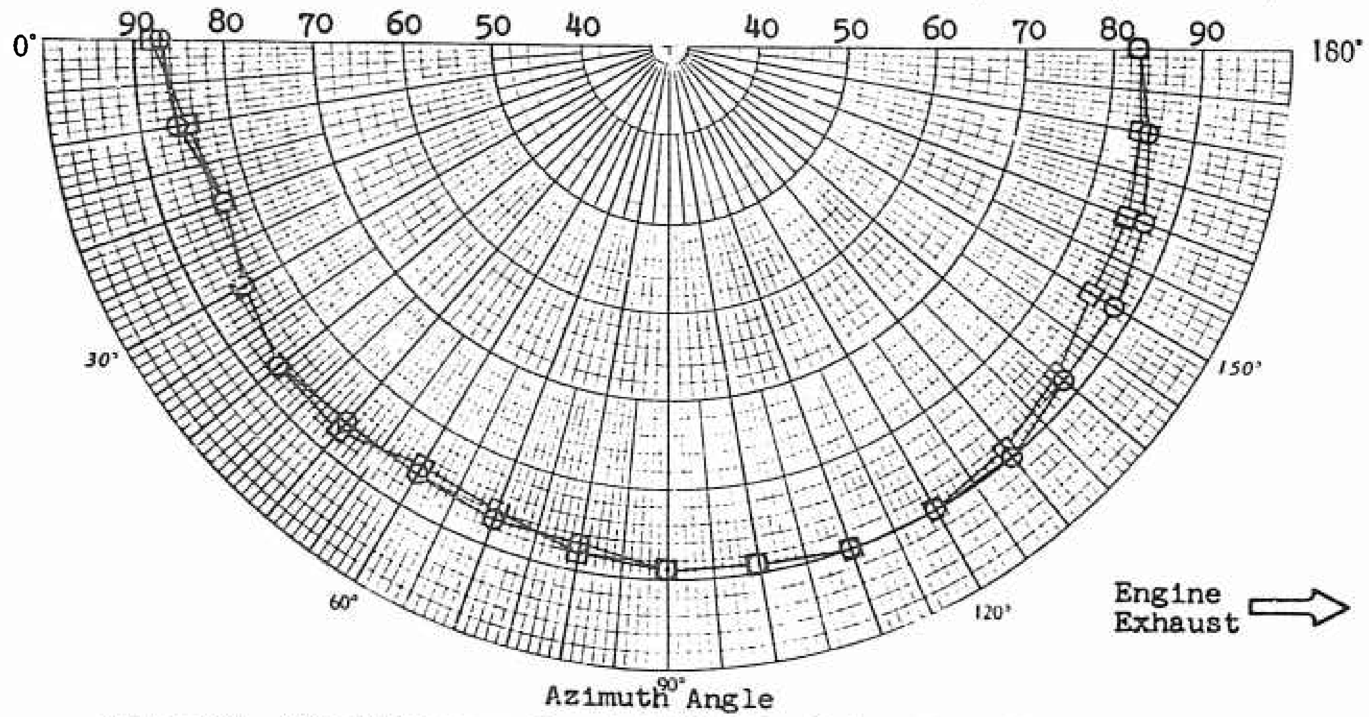


Figure 41. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 250 Hz.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46,008	35,000	191
□-□	250-E3 (Regenerative)	45,906	35,000	191

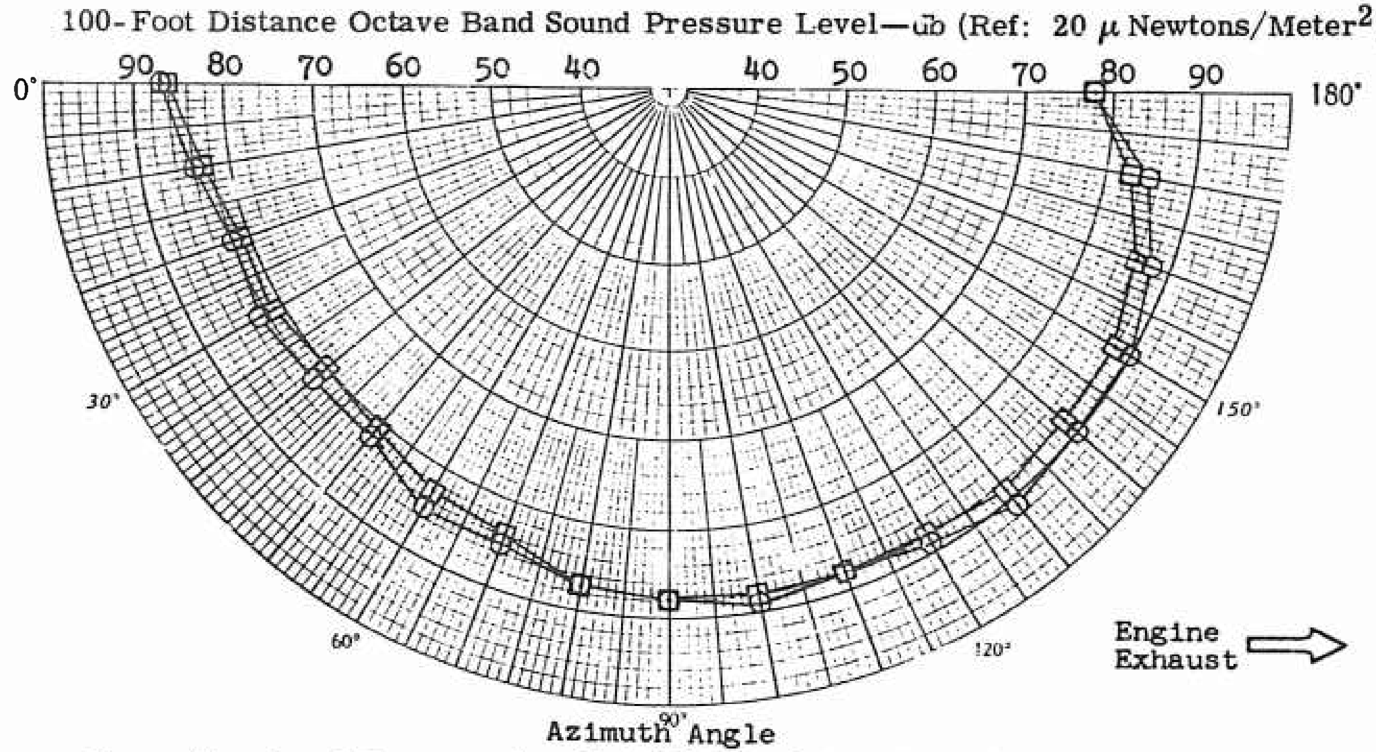


Figure 42. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 500 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

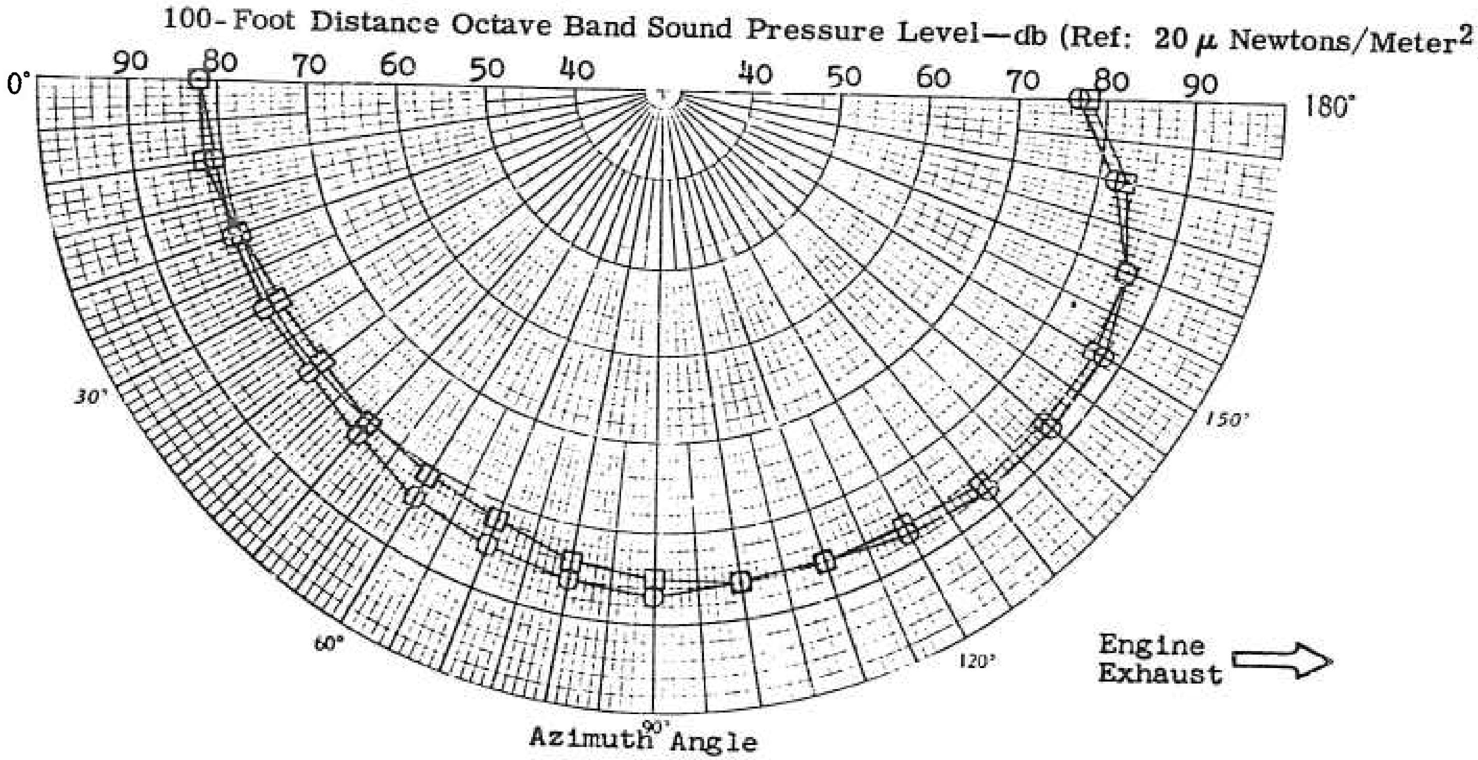


Figure 43. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 1000 Hz.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

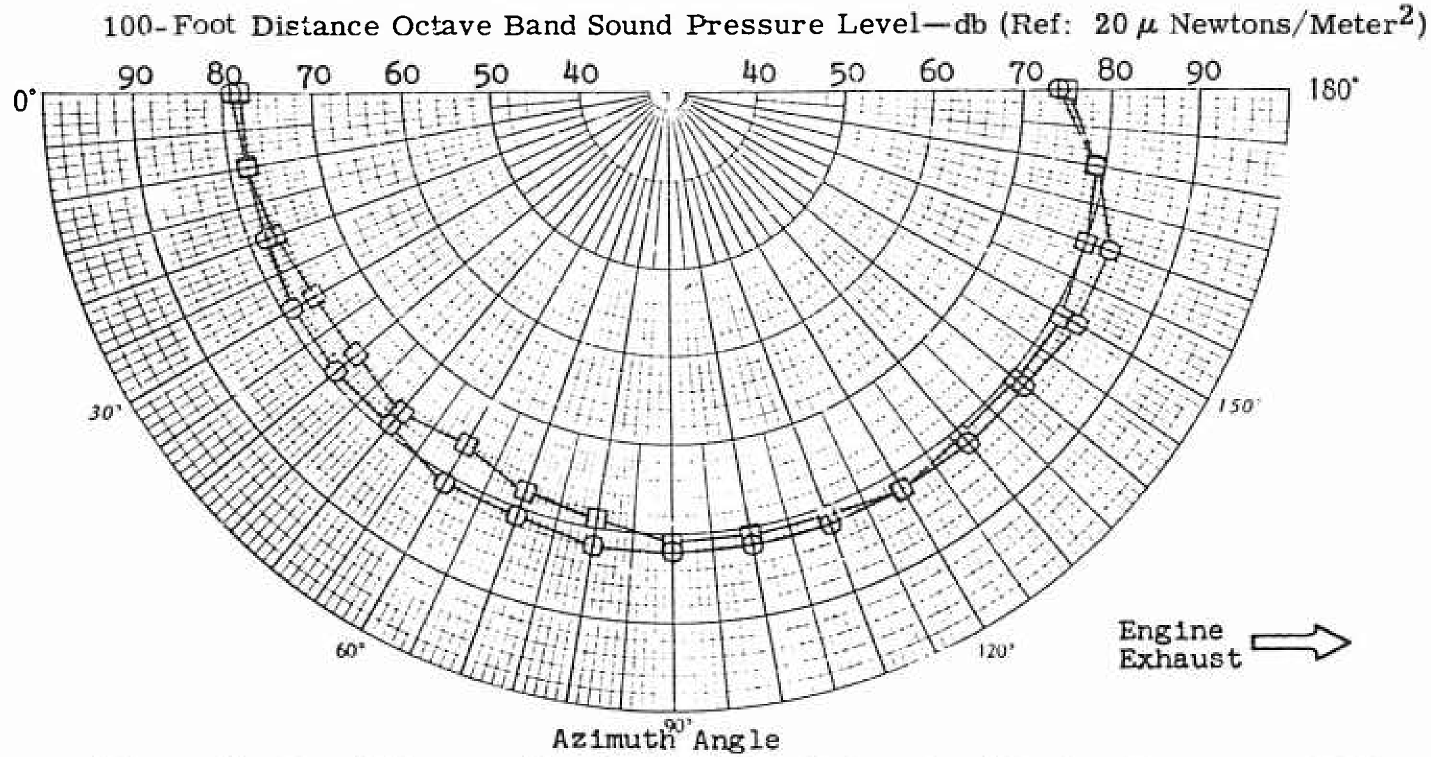


Figure 44. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 2000 Hz.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Pcwer (HP)
O—O	T63-A-5A (Nonregenerative)	46, 008	35, 000	191
□—□	250-E3 (Regenerative)	45, 906	35, 000	191

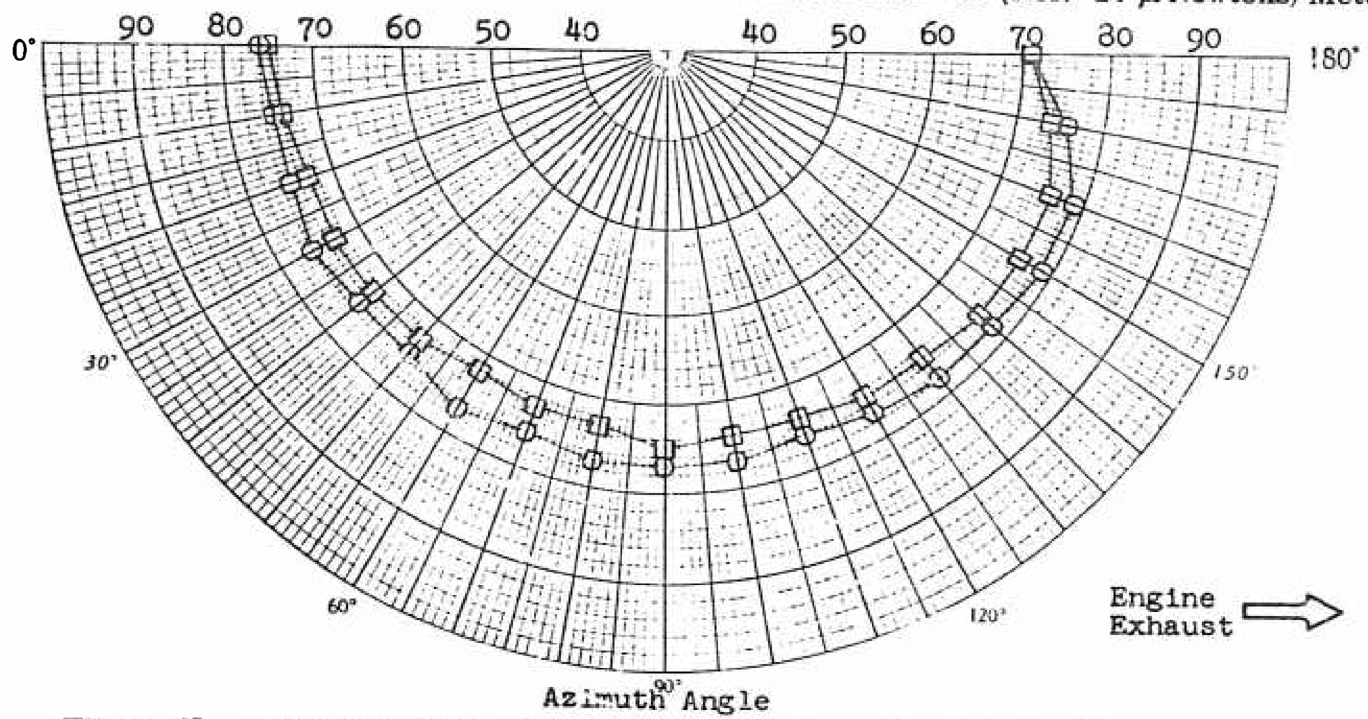


Figure 45. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 4000 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	46,008	35,000	191
□—□	250-E3 (Regenerative)	45,906	35,000	191

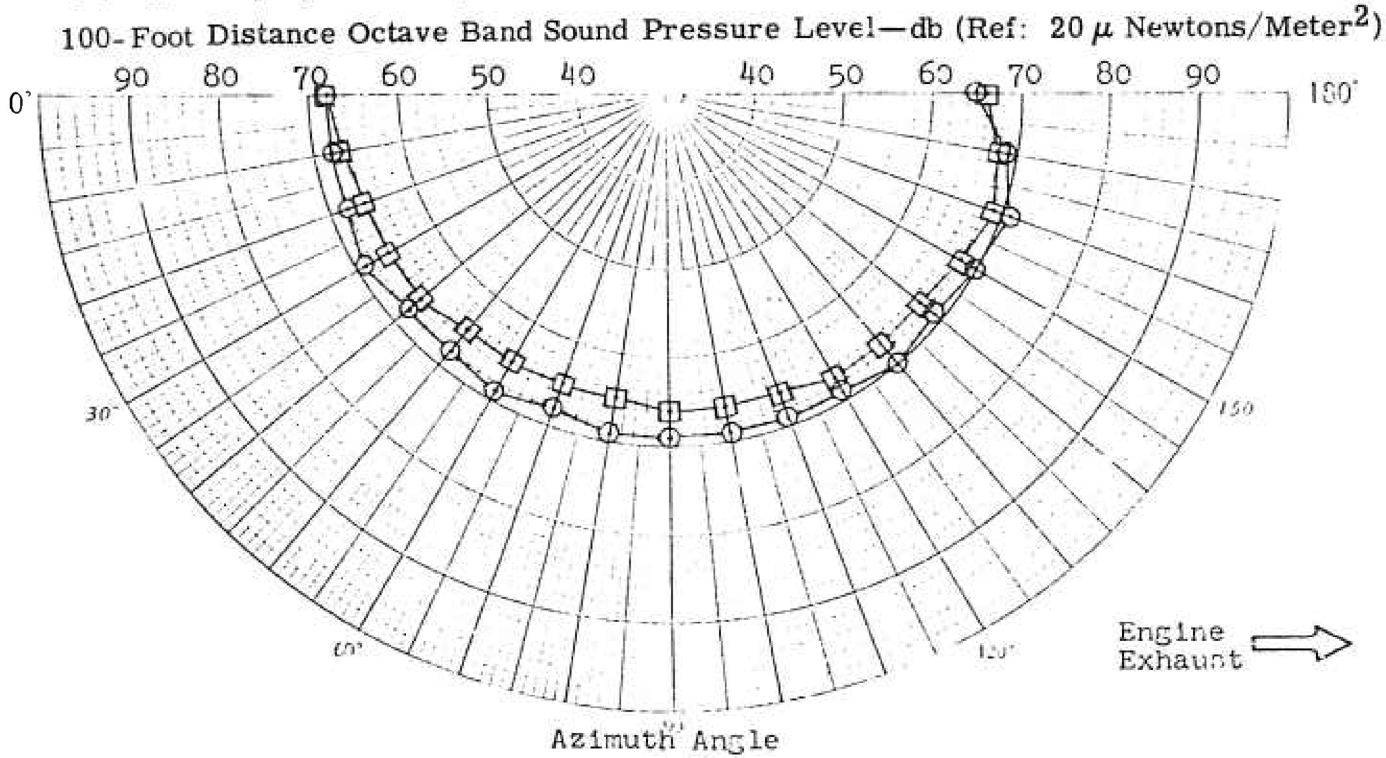


Figure 46. Sound Pressure Level at 191 HP—Octave Band Center Frequency = 8000 Hz.

Legend:	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31, 183	25, 200	29
□—□	250-E3 (Regenerative)	21, 980	25, 900	29

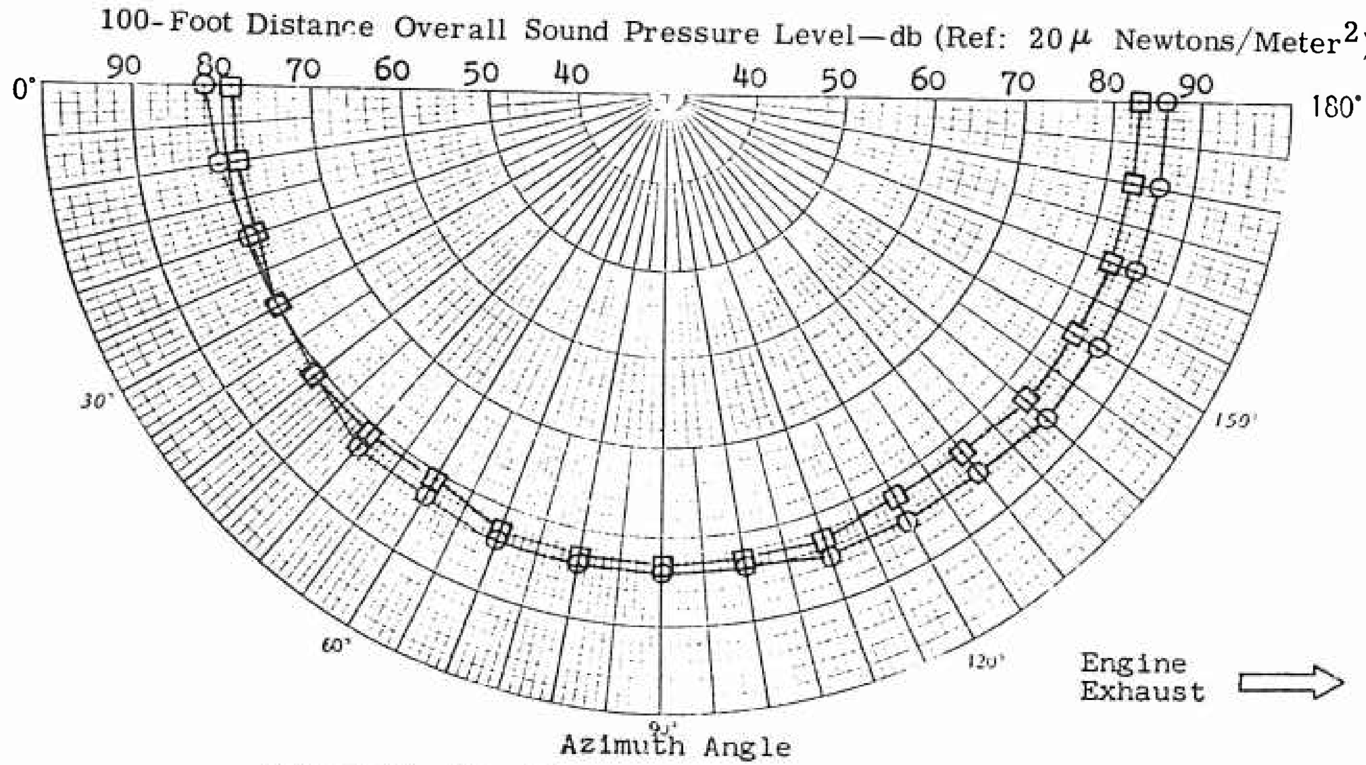


Figure 47. Sound Pressure Level at 29 HP—Overall.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

100-Foot Distance Octave Band Sound Pressure Level—db (Ref: 20 μ Newtons/Meter^2)

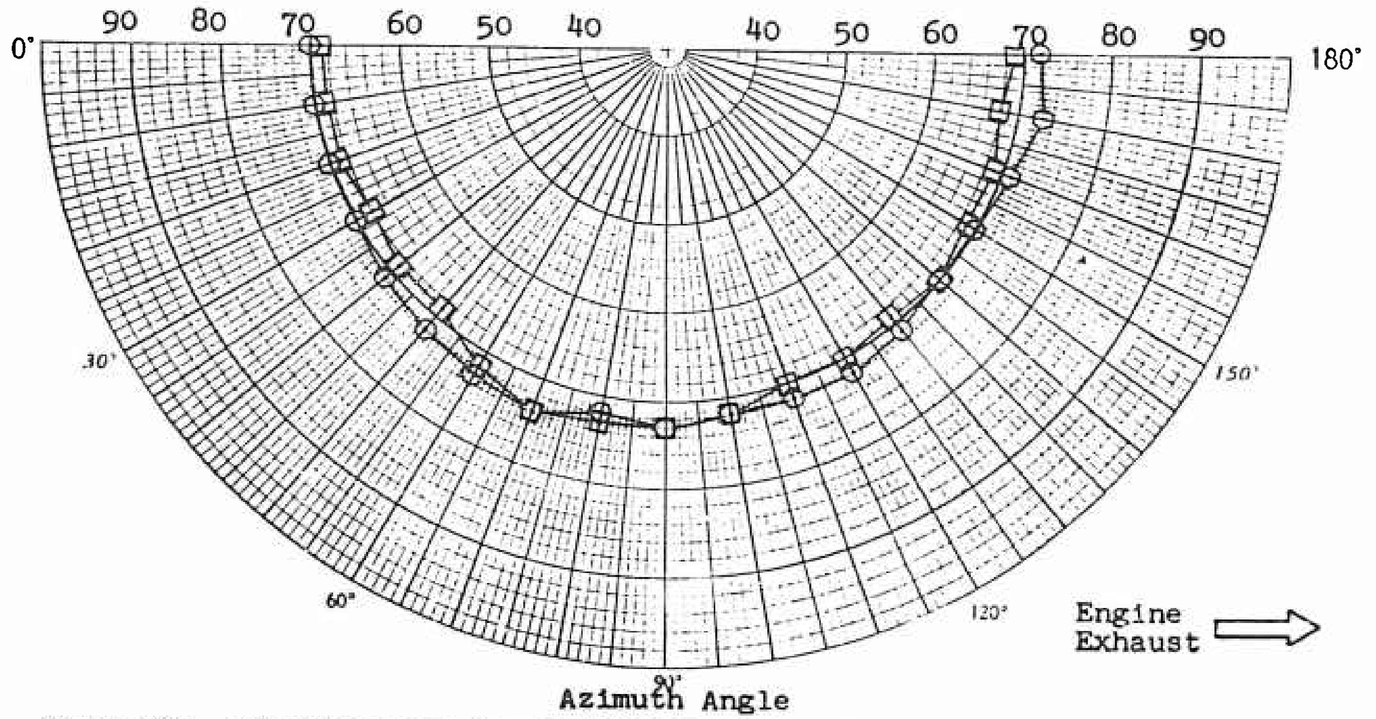


Figure 48. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 16 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

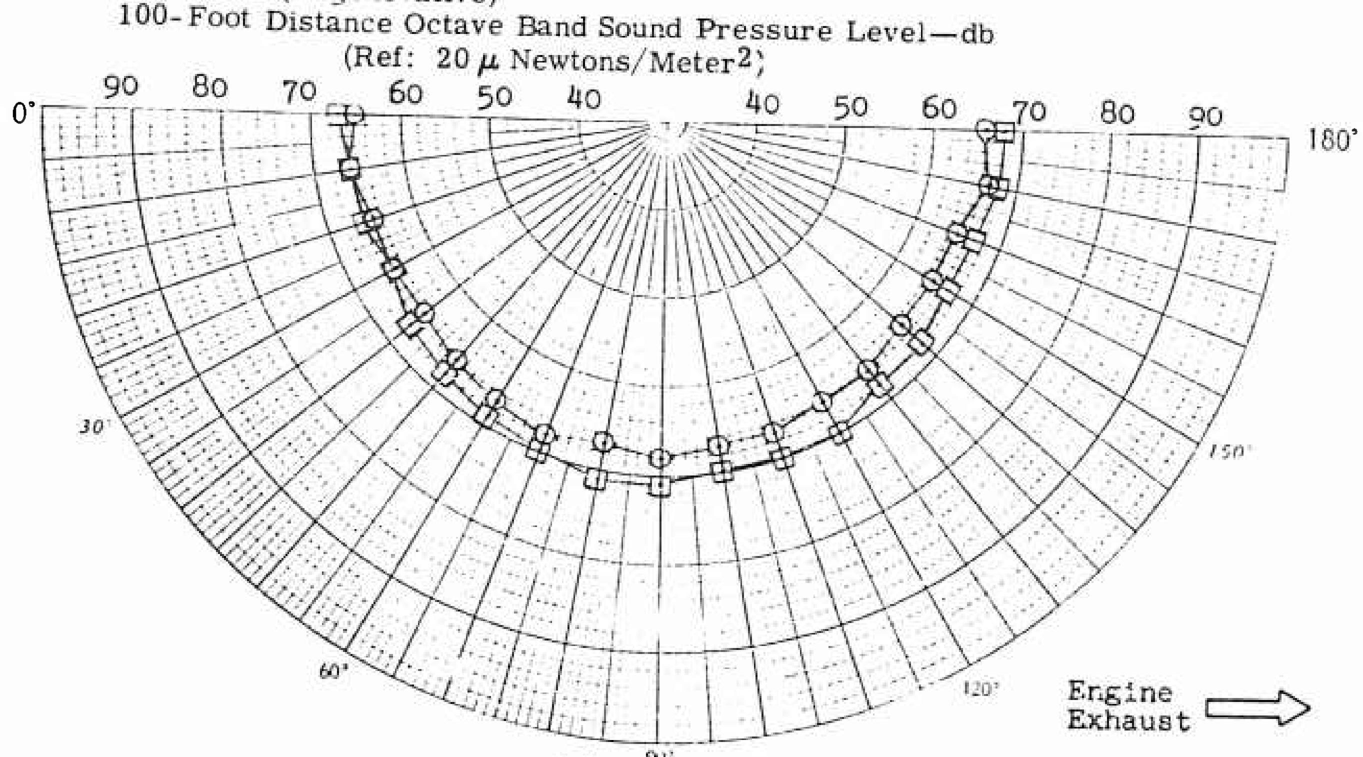


Figure 49. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 31.5 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

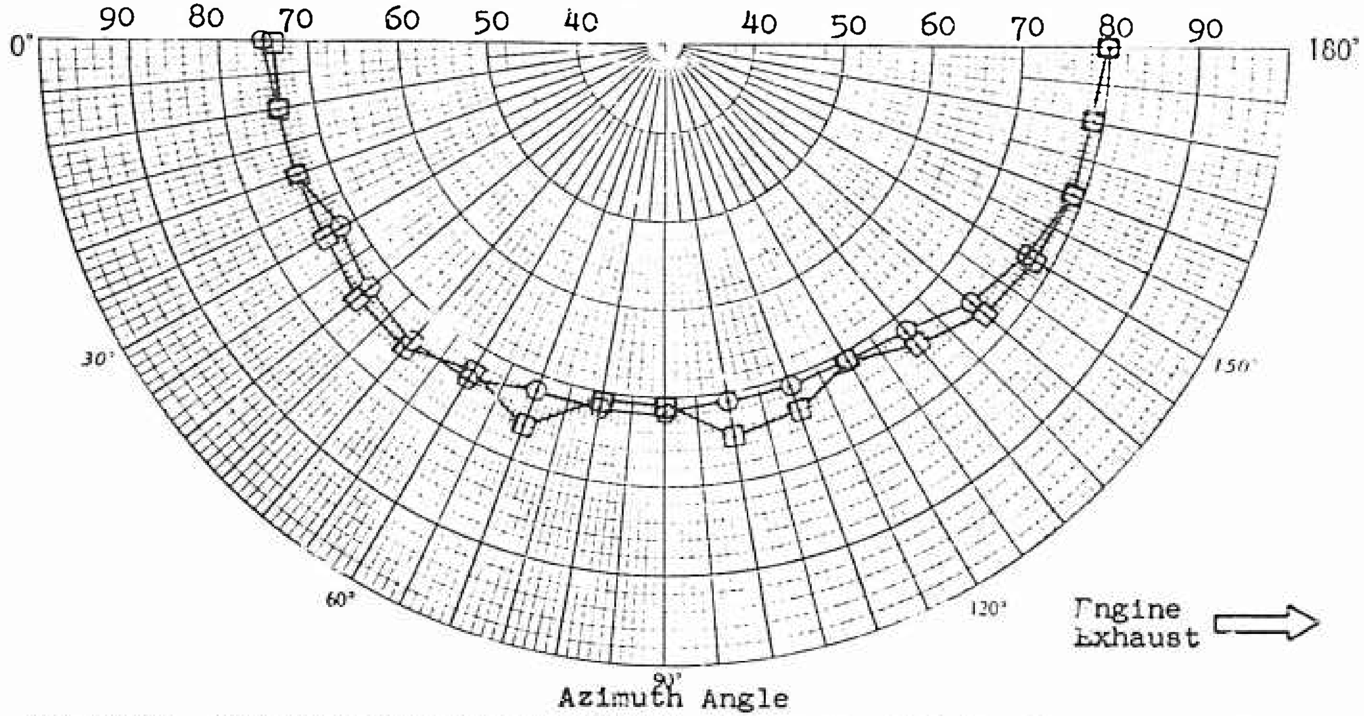


Figure 50. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 63 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

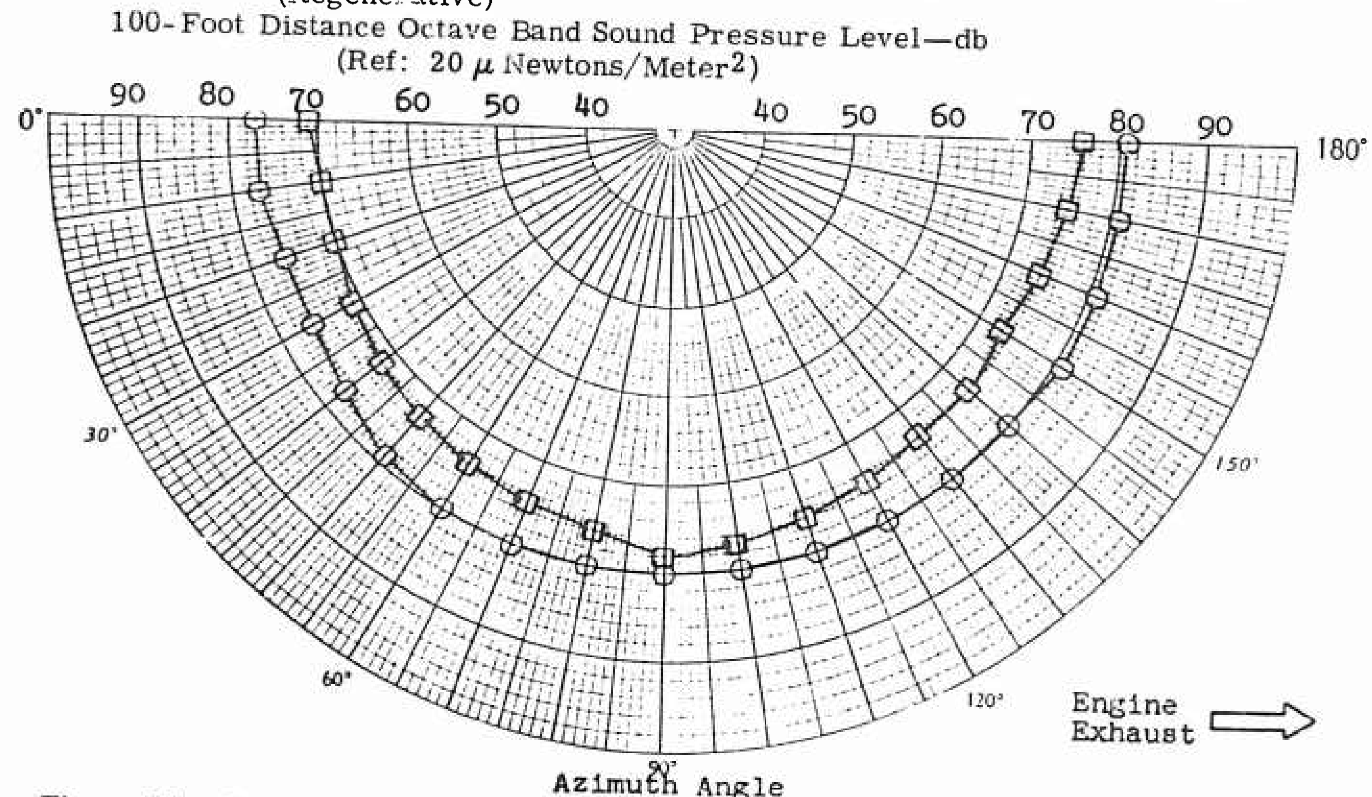


Figure 51. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 125 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31, 183	25, 200	29
□—□	250-E3 (Regenerative)	21, 980	25, 900	29

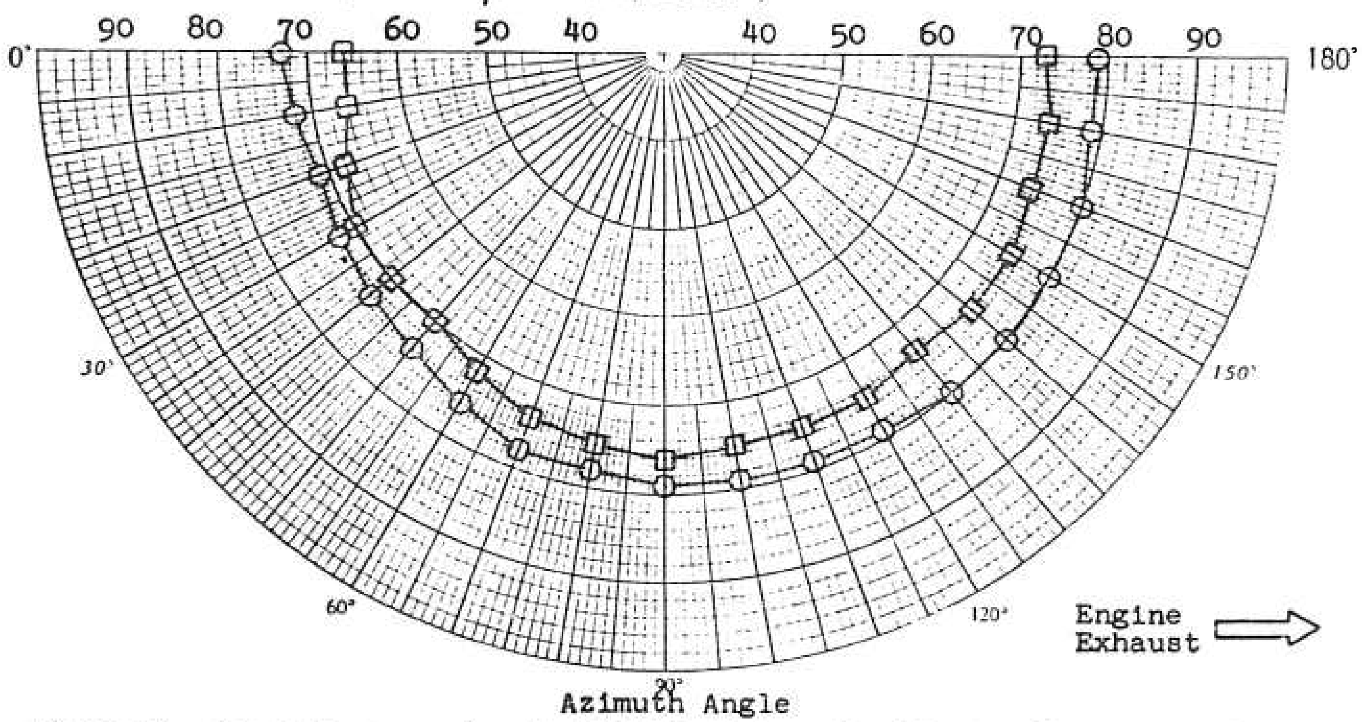


Figure 52. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 250 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31, 183	25, 200	29
□—□	250-E3 (Regenerative)	21, 980	25, 900	29

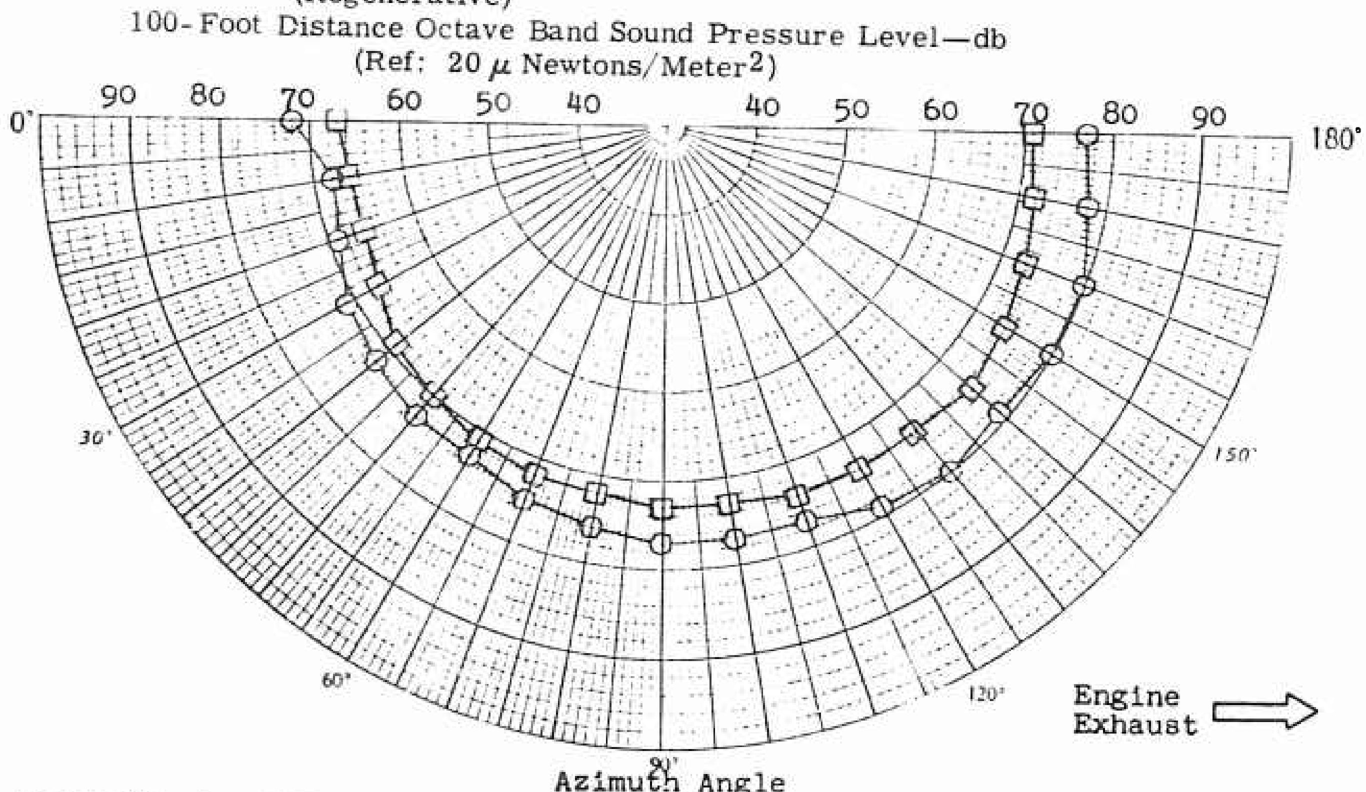


Figure 53. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 500 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerativ[illegible])	[illegible]1,980	25,900	29

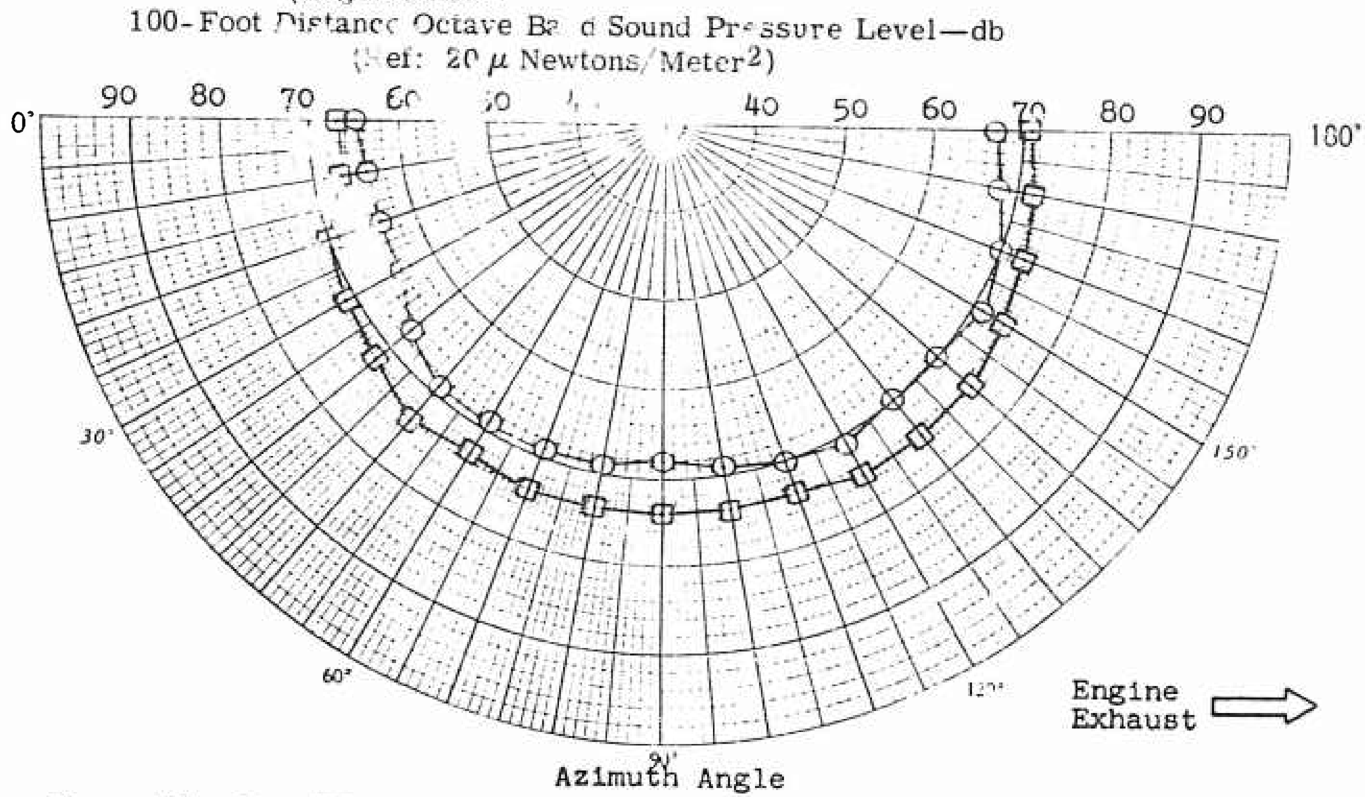


Figure 54. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 1000 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

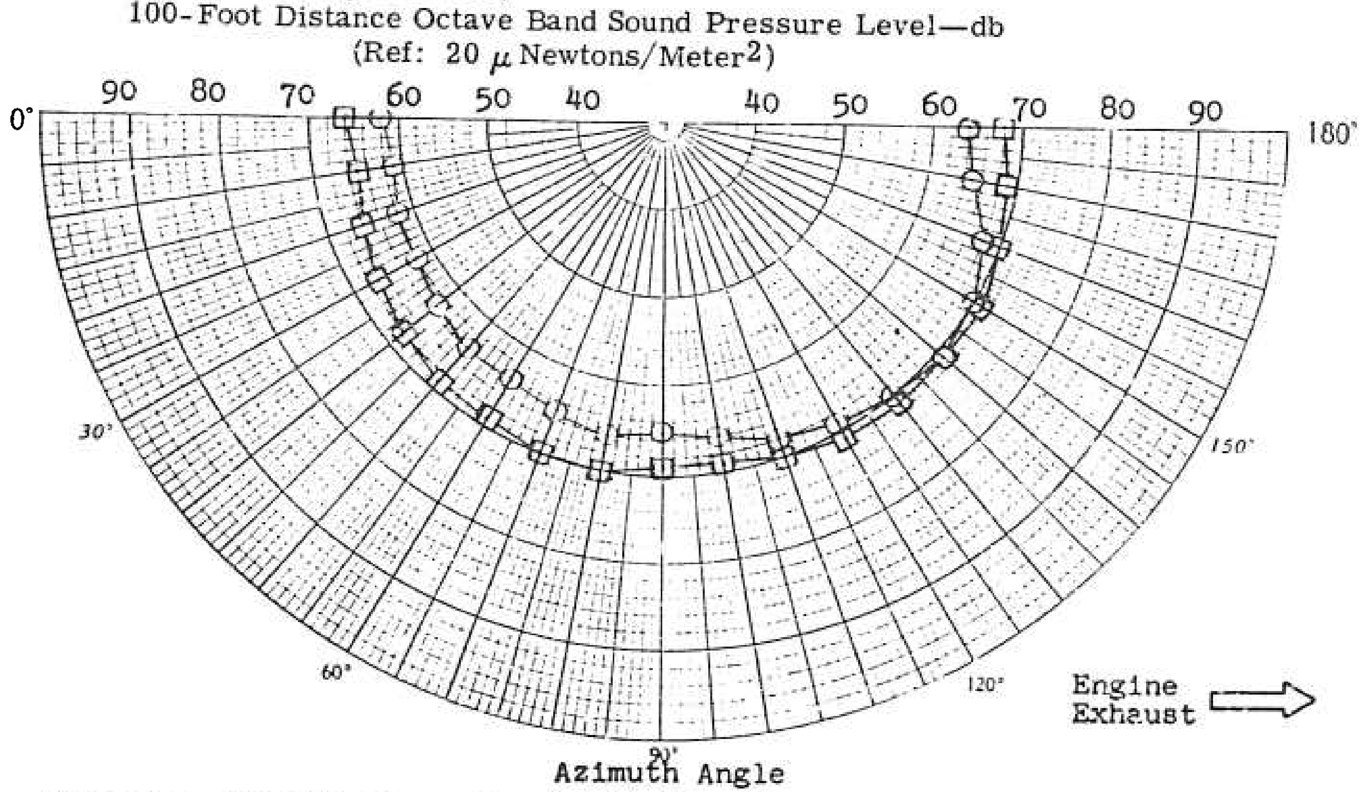


Figure 55. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 2000 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
○—○	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

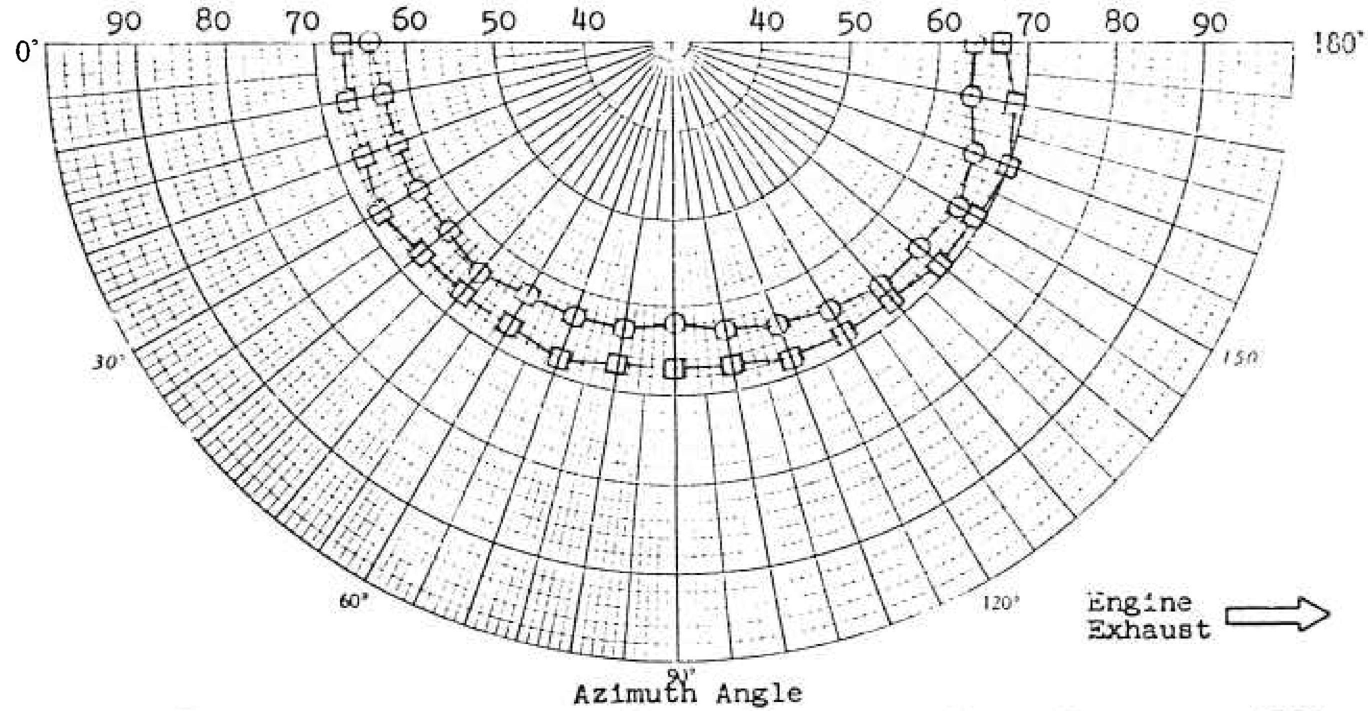


Figure 56. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 4000 Hz.

Legend:

	Engine Type	Gas Producer (N_1) Speed (RPM)	Power Turbine (N_2) Speed (RPM)	Shaft Power (HP)
O—O	T63-A-5A (Nonregenerative)	31,183	25,200	29
□—□	250-E3 (Regenerative)	21,980	25,900	29

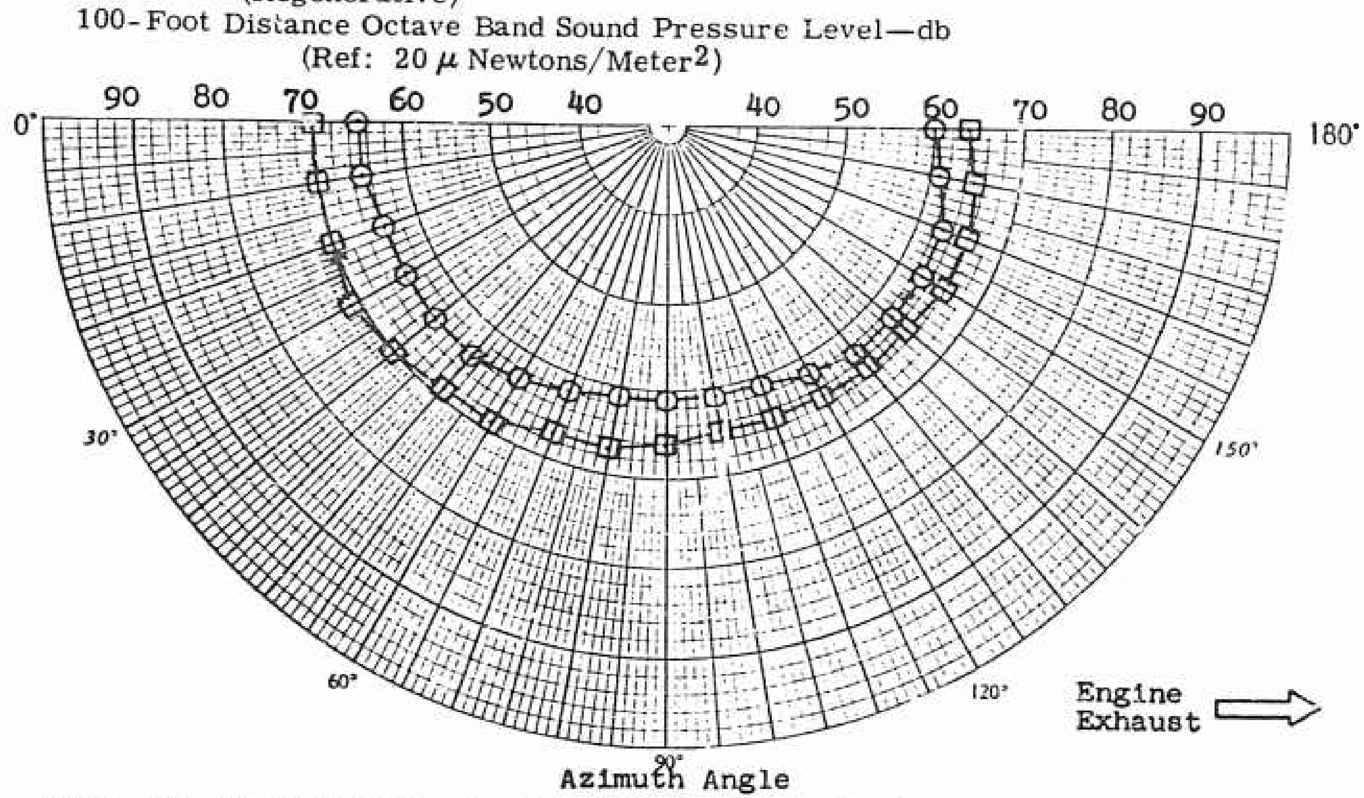


Figure 57. Sound Pressure Level at 29 HP—Octave Band Center Frequency = 8000 Hz.

SUMMARY OF RESULTS

1. The third set of regenerators successfully completed a 150-hour endurance test on the first attempt with no indication of regenerator performance deterioration or loss in structural integrity. The regenerators accumulated a total of 191 hours and in excess of 278 starts and 4500 accelerations. Overall engine performance was within the 5% allowable depreciation at the completion of the test.

2. The second set of regenerators completed the carbon fouling test with no performance depreciation. Engine performance after 3 hours' idle running was the same as the preendurance calibration. Carbon fouling was never a problem throughout the entire test program.

3. The second set of regenerators also successfully completed a 10-hour sand and dust ingestion test with no evidence of erosion or depreciation in regenerator performance. Overall engine depreciation was comparable to the depreciation encountered on the T63-A-5A without a regenerator. There were no leaks in any of the tubes or braze joints, and metallurgical examination showed no erosion or oxidation on any of the tubes. However, isolated tubes with braze on the inside diameter of the tube indicated incipient oxidation in the braze diffusion zone and on the surface of the braze.

4. The addition of a regenerator reduced the sound power level and perceived noise level one to three decibels. Even though the regenerator did produce measurable noise reduction, it is doubtful that the reduction would be noticed by a casual observer, since the two- to three-decibel high-frequency reduction is near the threshold of detection (15 to 20% noise change) and the change in exhaust noise would be masked by the unchanging rotor noise.

CONCLUSIONS AND RECOMMENDATIONS

The test data obtained during this program have demonstrated the feasibility of a regenerative engine as a powerplant for aircraft operation. There was no evidence of excessive performance depreciation, erosion, carbon fouling, or loss of structural integrity. The test results did not reveal any inherent design characteristics which indicate that the service life of the regenerators is not equivalent to that of the basic engine.

Future design studies for small gas turbines should consider the advantages of regeneration. Engine-aircraft design studies should be made to evaluate the effect of the lower required fuel capacity on overall aircraft design and performance. For those aircraft requiring infrared suppression, the reduced infrared signature of the regenerative aircraft can be taken into consideration when determining overall aircraft design and performance.

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13. ABSTRACT

This report is a supplement to USAAVLABS Technical Report 68-9. It covers the additional regenerative engine testing accomplished to determine environmental effects on the performance and structural integrity of the regenerators. The additional testing was done on the same hardware purchased under the original contract.

The third set of regenerators successfully completed a 150-hour endurance test on the first attempt with no indication of regenerator performance deterioration or loss in structural integrity. The regenerators accumulated a total of 191 hours and in excess of 278 starts and 4500 accelerations. Overall engine performance was within the 5% allowable depreciation at the completion of the test.

The second set of hardware successfully completed carbon fouling and sand and dust ingestion tests with no performance loss due to carbon fouling or any evidence of erosion or loss in structural integrity due to sand and dust ingestion.

The analysis of the sound survey data obtained under the original contract indicated that the regenerative engine perceived noise level was one to three decibels lower than that of the nonregenerative engine when installed in the YOH-6A helicopter.

The additional testing covered in this report again demonstrated the feasibility of a regenerative engine as a powerplant for aircraft operation. No problems were encountered which would indicate that a regenerative engine would be more susceptible to performance depreciation than the standard T63 engine.

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Regenerative Engine						
Tube-Shell Stationary Regenerator						
Endurance						
Carbon Fouling						
Sand and Dust Ingestion						
Sound Survey						

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